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The requirements for acquisition and logistics integration an examination of reliability management within the Marine Corps acquisition process

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THESIS

THE REQUIREMENT FOR ACQUISITION AND LOGISTICS INTEGRATION: AN EXAMINATION OF RELIABILITY MANAGEMENT WITHIN THE MARINE CORPS ACQUISITION PROCESS

by

Marvin L. Norcross, Jr.

December 2002

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13. ABSTRACT *(maximum 200 words)*

Combat system reliability is central to creating combat power, determining logistics supportability requirements, and determining systems' total ownership costs, yet the Marine Corps typically monitors only operational availability. While acceptable operational availability may be achieved through intensive maintenance and the stocking of needed repair parts in large quantities, this increases the logistics burden on the combat commander and is costly in terms of personnel, time, and funding.

Data required to compare system reliability requirements in source documents, such as the Operational Requirements Document and the acquisition contract, to achieved reliability of fielded systems is generally not collected, maintained, or available. Contractual obligations to attain system reliability, if any, could not be enforced, and any increase in sustainability costs associated with unmet reliability thresholds is borne by the Marine Corps, draining scarce funding from other priorities.

This research interprets data and perspectives, as collected from a reliability management survey administered to acquisition workforce professionals, and collectively summarizes common inhibitors of effective reliability management, why they occur, lessons learned, and potential methods for mitigating the inherent risks. The results ascertain a variety of technical, programmatic, managerial, incentive, and procedural issues that the Marine Corps encounters concerning system reliability requirements and achievement.

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THE REQUIREMENT FOR ACQUISITION AND LOGISTICS INTEGRATION: AN EXAMINATION OF RELIABILITY MANAGEMENT WITHIN THE MARINE CORPS ACQUISITION PROCESS

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I. INTRODUCTION

A. BACKGROUND DISCUSSION

In today's environment of aging weapon systems, there is an increased need for Operations & Support (O&S) funding. However, because of DoD budgetary constraints, there has been a trend in recent years to utilize discretionary modernization funds in an effort to fund shortfalls in O&S accounts. As a result, DoD's current acquisition approach is to acquire products and services to meet military needs that will provide the best value to the government over the life cycle of the product or service. Consequently, performance parameters, to include reliability achievement, must be considered in relation to Total Ownership Costs (TOC) vice simply considering the initial procurement costs of weapon systems.

Acquisition decisions made early in the life cycle of weapon systems can have a tremendous impact on the availability and sustainment of Marine Corps equipment. Thus, highly reliable systems are extremely important as they serve as force effectiveness multipliers that significantly contribute towards increased system availability, a reduced logistical footprint, and a net reduction in total ownership costs, which equate to increased funds for modernization. Therefore, it is imperative that a primary goal of systems acquisitions is to field reliable equipment that is both capable and supportable from the start.

Both the inherent reliability designed into weapon systems and the estimates of such reliability have significant impacts on weapon system readiness and cost for decades as the reliability estimates provide the basis for initial life-cycle supportability decisions, including integrated logistical support packages. Specifically, such estimates contribute to determining the initial procurement of spare parts and support equipment, concept of logistical support, the number and training of mechanics, readiness estimates, operation and support costs, and Program Objectives Memorandum (POM) planning. Therefore, the effect of low inherent reliability, as well as the effect of under- or over-estimating the reliability of weapon systems, will cause already limited dollars to be allocated unwisely as unanticipated life cycle costs accumulate and cause an additional need for O&S dollars

in later years. Consequently, it is imperative to obtain, verify, and utilize accurate reliability forecasts early in the life cycle process and to attempt to tie contractors to readiness and LCC thresholds through reliability estimates.

Fortunately, there are many early opportunities for addressing reliability within weapon systems acquisitions. Initially, the Requirements Generation Process can serve as a primary tool for the Marine Corps to document quantifiable system reliability requirements in the Operational Requirements Document (ORD) in the form of Key Performance Parameters (KPP). Additionally, the reliability requirements can be used in source selection as we convert specific performance specifications into contractual terms, which could perhaps include an inherent reliability goal. From here, the Systems Engineering Process allows the contractor to build to such required performance specifications. Additionally, once contractors submit their reliability estimates, program planning and organizational management can emphasize an independent and rigorous reliability testing process throughout the development phase in order to demonstrate the required reliability performance levels to ensure the system will operate in the field as intended. Lastly, while not an upfront opportunity, comparison and assessment of achieved field reliability to contractor reliability estimates could be conducted throughout weapon system maturation to ensure attainment of system reliability as planned.

However, due to procedural, management, and incentive issues, the Marine Corps is faced with inhibitors to effective reliability management, and thus, the acquisition community has not been able to fully take advantage of such reliability management opportunities. Ultimately, as a result, the warfighter is not provided with a reliable and supportable weapon system that is capable of being sustained within its life cycle cost threshold.

B. OBJECTIVES AND PURPOSE OF THE RESEARCH

The purpose of this research is to evaluate how weapon system reliability performance is managed throughout the acquisition process by identifying common inhibitors and enablers of effective reliability management, why they occur, lessons learned, and potential methods for mitigating the inherent risks. The results of the thesis are intended to directly benefit Program Managers while providing insight into the improved sustainability of future systems. Understanding that reliability estimates

provide the basis for initial life cycle supportability decisions, the acquisition community must utilize effective procedures, as well as develop management strategies and techniques to address reliability risks. The research ascertains procedural issues that the Marine Corps deals with concerning reliability requirements in the acquisition process as well as common management and incentive issues faced by program management offices. The resulting analysis includes conclusions and recommendations applicable to the acquisition community.

C. RESEARCH QUESTIONS

1. Primary Research Question

- What strategies should be used to better manage weapon system reliability during the life cycle of major weapon systems?

2. Subsidiary Research Questions

- How does reliability affect Life Cycle Cost and Operational Availability?
- What are the existing policies, regulations, and guidance that govern reliability of weapon systems available to the Combat Developer, Program Management Office, and Contractor? Do they provide adequate guidance?
- How does the Marine Corps address reliability performance of weapon systems during the Requirements Generation Process?
- How can the Marine Corps create and adhere to a contractual obligation in the form of quantitative system reliability requirements that forces contractors to consider reliability equally with other system parameters such cost, schedule, and performance?
- How is system reliability addressed during developmental and operational testing, and is the Marine Corps adequately testing to determine and demonstrate the required reliability performance levels?
- Is there a significant difference between contractors' reliability estimates and achieved reliability of fielded systems as obtained from Marine Corps logistics systems, and if so, is the Marine Corps adequately assessing the data during the maturation of weapon systems in order to alleviate future contractor reliability inaccuracies?
- Is the Marine Corps maintenance rate, in the form of MTBM, a feasible surrogate for comparison with traditional failure rate, in the form of MTBF, as obtained from contractors?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The research for this thesis was completed in collaboration with a similar concurrent study conducted by Studies and Analysis Division, Marine Corps Combat

Development Command (MCCDC) under the sponsorship of Marine Corps Systems Command (MARCORSYSCOM), entitled "Sustainment Consequences of Acquisition Decisions." The thesis assesses pre-fielding programmatic and technical decisions that influence reliability of fielded systems (MARCORSYSCOM study plan "Sustainment Consequences . . ."). Specifically, the scope of this research includes an evaluation of reliability management within the Marine Corps acquisitions process from numerous perspectives to include: 1) a review of the relationship between reliability, operational availability, logistics support, and life-cycle costs, 2) a review and assessment of current DoD and Marine Corps policy, guidance, and regulations regarding reliability, 3) an examination of reliability requirements documentation and its relevance in source selection, 4) an assessment of transforming ORD reliability performance specifications into contractual obligations, 5) an evaluation of the extent to which reliability requirements are being demonstrated during testing, 6) a comparison and assessment of reliability requirements and contractor reliability estimates to actual achieved reliability of fielded systems, and 7) an analysis of the Marine Corps' adequacy of comparing and assessing the aforementioned data during the maturation of weapon systems. The research will aide in assessing the accuracy and completeness of reliability estimates for fielded systems while identifying techniques to improve the accuracy of reliability estimates during systems development. Furthermore, a comparison of documented reliability requirements and pre-fielding estimates to achieved reliability will provide beneficial insight into achieving future readiness (MARCORSYSCOM Draft SOW "Sustainment Consequences . . .").

The data collected is limited to mature Critical/Pacing items included in the Quarterly Readiness Reports to Congress (M1A1 tank, AAV family of vehicles, LAV family of vehicles, 5-ton truck family of vehicles, HMMWV family of vehicles, LVS family of vehicles, and the M198 Howitzer). The analysis is limited to an assessment of reliability management issues, while not specifically addressing technology driven reliability problems. While the research is limited to selected principle end items, it is assumed that the challenges, issues, and potential solutions can be applied to other end items in the Marine Corps acquisition process.

E. METHODOLOGY

In an effort to determine the current environment for reliability management within Marine Corps acquisitions, the researcher administered an electronic survey (Appendix B) to various personnel within the Program Offices of specific critical/ pacing end items. The questions posed were intended to emphasize the perspective of program management leadership on the varied tasks involved with reliability management (Masiello, p. 4). Specifically, the survey was intended to conduct an examination of current policy and regulations, reliability requirements documentation, contractual obligations, developmental and operational test data, and readiness/maintenance data. The survey utilized was a modification of a previously designed reliability performance survey intended to gather data within a specific Army Program Executive Office in pursuit of similar research objectives (Ryan, pp. 91-97).

The methodology used in this thesis research consisted of the following steps:

- Through a review of existing publications, examine and document the relationship between reliability, logistics, life-cycle support costs, and readiness
- Review and examine the adequacy of current DoD and Marine Corps policy, guidance, and regulations that govern reliability
- Conduct a review of the acquisition process, from determining needs requirement through sustainment operations and support
- Through the combination of data collection from the Fleet and reliability survey responses from the acquisition community:
  - Determine the extent to which the Marine Corps organizations involved throughout the acquisition process consider reliability
  - Determine how the Marine Corps addresses reliability performance in the requirements generation phase
  - Review the current process and methods of transforming ORD requirements into quantifiable contractual obligations
  - Determine the extent to which reliability requirements are demonstrated during testing
  - Determine if contractor reliability estimates are retained, and determine the achieved reliability data of mature fielded systems
  - Compare and assess the predetermined reliability requirements and contractor estimates to achieved reliability of mature systems. Determine and evaluate the Marine Corps' adequacy at conducting

the same comparison throughout the maturation of weapon systems.

- Assess the collected data to identify policy, managerial, and procedural issues involved with current reliability management in the acquisition process
- Recommend policy and procedural changes to reliability management throughout the acquisition process and provide insight into the improved sustainability of future systems through the obtainment of accurate reliability estimates from contractors

F. ORGANIZATION OF THE RESEARCH

This thesis contains six chapters.

Chapter I introduces the subject of reliability as a basis for the study while providing the objectives, scope, methodology, organization, and benefits of the research.

Chapter II provides a background and overview of reliability while defining reliability and related concepts. The relationship between reliability, logistics, life-cycle support costs, and operational availability will be addressed. Additionally, this chapter discusses the tools and techniques available for reliability analysis.

Chapter III is a brief overview of the acquisition process from the Requirements Generation Process through Sustainment Operations and Support. Additionally, this chapter discusses the participants and organizations involved in the process. Also, the current DOD and Marine Corps policies, regulations, and guidance that establish the basis within which the acquisition community should operate to manage reliability within a program will be discussed.

Chapter IV provides the program demographics and background of the systems that are a part of this study and presents the aggregate results of the data collection from the reliability survey. This data indicates how the respective programs have implemented reliability management processes and highlights significant examples and experiences.

Chapter V analyzes and compiles the key issues and challenges associated with reliability to include issues with existing policy and guidance on reliability, reliability requirements determination and documentation, contracting for reliability, developmental and operational testing, and comparison and assessment of reliability requirements and estimates to achieved reliability.

The final chapter makes conclusions and recommendations, provides answers to the primary and secondary research questions, and recommends areas for further research.

G. BENEFITS OF THE RESEARCH

According to Marine Corps Systems Command, there are currently no known studies within the Marine Corps comparing the relationship of reliability, availability, and maintainability (RAM) to Operational Availability and determining its impact on Future Readiness thresholds (MARCORSYSCOM Draft SOW "Sustainment Consequences . . .", p. 3). Thus, the primary benefit of this study is the identification of policy and program management issues with respect to weapon system relia bility and providing recommendations for areas of potential improvement. The research is intended to directly benefit the acquisition community by identifying common potential inhibitors, identifying their underlying root causes, providing lessons learned, and suggesting methods for managing and reducing inherent risks associated with achieving reliability performance requirements. Additionally, attaining accurate contractor reliability estimates, used as a basis for initial life cycle supportability issues, will benefit the Marine Corps by optimizing the use of constrained resources and improving the operational force materiel readiness posture (MARCORSYSCOM Draft SOW "Sustainment Consequences . . .").

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II. RELIABILITY OVERVIEW AND BACKGROUND

> When in a fight to the death, one wants to employ all one's weapons to the utmost. I must say that to die with one's sword still sheathed is most regrettable. – Miyamoto Musashi, Book of Five Rings

A. INTRODUCTION

The purpose of this chapter is to provide a fundamental understanding of reliability and its importance within weapon systems acquisitions. This will be accomplished by addressing the relationship between reliability, logistics, life-cycle support costs, and operational availability. However, an overview of reliability and related concepts will first be required to provide a common frame of reference and establish a general basis of understanding for subsequent discussions. Accordingly, this chapter also discusses the alignment of process ownership between the Program Management/Weapon System Management (PM/WSM) and Supply Chain Management (SCM) organizational elements while detailing the changes recently implemented within the Marine Corps to best accommodate life cycle management of its equipment. Lastly, tools available for reliability analysis will be briefly introduced.

B. RELIABILITY DEFINED: RELATED DEFINITIONS, CONCEPTS, AND MEASURES

In order to address the role of reliability in the logistics community, it is imperative to understand the terms and definitions most widely associated with defining and discussing reliability. The intent of this section is to provide basic quantitative and qualitative knowledge of reliability-related definitions and concepts required to plan for, design, produce, and implement an effective and efficient logistic support capability. Of particular emphasis within weapon systems acquisitions are the qualitative measures of reliability and logistics, which must be addressed in order to ensure logistics requirements are adequately specified, evaluated, and modified for improvement. In addition to reliability itself, other measurements are utilized to characterize the reliability of a system and its components.

1. Reliability

The probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions (Blanchard, p. 25).

- When considering component reliability, the term “system” can be extended to include components or subsystems that can be considered as an entity
- The term “satisfactory” indicates that specific criteria must be established to determine what satisfactory operation/service is
- For a hardware item to be reliable it must do more than meet an initial factory performance requirement – it must operate for a given period of time in the actual application for which it is intended. “Time” represents a measure against which the degree of system performance can be related.

Inherent reliability is the potential reliability of a system (inherent as designed), assuming an ideal operating and support environment.

As evident from the preceding clarifications, the concept of reliability is often utilized without precise definition, while the terminology is non-standard throughout the logistics community and tends to depend on the Service and/or system. In the broadest sense, reliability is associated with dependability, with successful operations, and with the absence of breakdowns or failures (Lewis, p. 1). However, while creating DoD requirements documentation and contract specifications, it is very important that all main concepts are addressed in an unambiguous way so that all parties involved understand the terms. Furthermore, to adequately conduct engineering analyses, reliability must be defined quantitatively as a probability. Thus, one must consider the time parameter in order to assess the probability of completing a given function as scheduled. The reliability function, *R(t)*, may be expressed as:

$$R(t) = \Pr(T > t) = \int_t^\infty f(t)\,dt = 1 - F(t) \qquad (2.1)$$

Let *T* be a random variable that represents the time until the next failure, *f(t)* be the probability density function, and *F(t)* be the cumulative density function of *T*.

Then the reliability function, *R(t)*, is defined as the probability that the failure will not occur until time *t*.

Assuming that the time to failure is described by an exponential density function, the reliability function, *R(t)*, is:

$$R(t) = \Pr(T > t) = \int_t^\infty f(t)\,dt = 1 - F(t) = \int_t^\infty l e^{-lt} dx = e^{-lt} \tag{2.2}$$

where t is the time period of interest, and e is the natural logarithm base (2.7183), and l is the instantaneous failure rate (Blanchard, p. 37). It is important to note that the reliability function as depicted above is in terms of an exponential distribution. This means that the unit's failure rate is constant over the period t, the reliability for a new mission is independent of the age of the unit and is a function of its failure rate and the duration of the new mission only. This is commonly used in many applications under the presumption that all like components are being utilized in the exact same manner with the same stresses imposed upon them. In reality, the failure characteristics of different components vary considerably depending upon their usage. Other applicable density functions include the normal, binomial, exponential, Poisson, gamma, and Weibull distributions (Kececioglu, p. 202). However, explanation of such distributions are beyond the scope of this thesis.

2. Failure Rate

> The number of item failures of per measure of unit life, where failure is defined as the termination of an item's ability to perform a required function (Hoyland and Rausand, p. 10).

The failure rate is expressed as:

$$l = \frac{number of\ failures}{total operating hours} = \frac{1}{MTBF} \tag{2.3}$$

When determining overall failure rate, it is important to address all system factors that cause the system to be inoperative at a time when satisfactory system operation is required. A combined failure rate is presented in Table 2.1.

Consideration	Assumed Factor (instances/hour)
(a) Inherent reliability failure rate	.000392
(b) Manufacturing defects	.000002
(c) Wear-out rate	.000000
(d) Dependent failure rate	.000072
(e) Operator-induced failure rate	.000003
(f) Maintenance-induced failure rate	.000012
(g) Equipment damage rate	.000005
Total combined factor	.000486

Table 2.1. Combined Failure Rates. (From: Blanchard, p. 40)

3. Mean Time Between Failure (MTBF)

For a particular interval, the total functional life of a population of an item divided by the total number of failures with the population (DSMC, "Acquisition Logistics Guide", p. 10-2).

MTBF serves as the basic technical measure of reliability, and thus, the measure becomes a key element in support planning. In simplified terms, MTBF is the average time between required corrective (unscheduled) maintenance actions. MTBF should not be used interchangeably with failure rate, and in fact, MTBF is the inverse of the failure rate:

$$MTBF = \frac{1}{l} \tag{2.4}$$

It is important to distinguish why MTBF needs to be calculated for equipment. The calculation of this time is necessary in order to determine whether the mean time between failures is increasing, decreasing, or remaining constant with age. As equipment ages, its MTBF decreases until the cost of keeping that item operational is more than the cost of buying a new item. Estimates of when maintenance costs will exceed acquisition

costs are questionable without mean time between failure calculation (Enholm, p. 1). In other words, MTBF data analysis can help to determine if equipment is in the "wear-out" phase of its life cycle and at the end of its economic useful life.

4. Mean Time Between Maintenance (MTBM)

MTBM includes both preventive (scheduled) and corrective (unscheduled) maintenance requirements. It includes consideration of reliability MTBF and MTBR. MTBM may also be considered as a reliability parameter and can be expressed as:

$$MTBM = \frac{1}{\dfrac{1}{MTBM_{unscheduled}} + \dfrac{1}{MTBM_{scheduled}}} = \frac{1}{l + fpt} \qquad (2.5)$$

where *fpt (=1/MTBM$_S$)* is the frequency of the preventive maintenance actions per system operating hour, or the preventive maintenance rate. Also, $MTBM_{unscheduled}$ (same as MTBF) is the mean interval of unscheduled maintenance and $MTBM_{scheduled}$ is the mean interval of scheduled maintenance (NPS Logistics Engineering principle).

It should be obvious that MTBM is not the same measurement as MTBF due to the inclusion of preventive maintenance actions. However, the Marine Corps is often forced to substitute MTBF with MTBM due to lack of operational usage data needed to calculate MTBF. The feasibility of this substitution will be discussed in more thorough detail later in the thesis.

5. Availability

> The probability that an item (system) is in an operable and committable state at the start of a mission when the mission is called for at a random point in time. "Is the equipment available in a working condition when it is needed?" (DSMC, "Acquisition Logistics Guide", p. 10-3)

Availability is frequently used as a measure of system readiness, and thus, the user is often most concerned about this parameter. There are numerous expressions of availability, all of which are based on the standard mathematical relationship between "up time", "down time", and "total time." In other words, over long operating periods, availability can essentially be expressed as a relationship between uptime (reliability) and downtime (DSMC, "Designing Quality into . . .", p. B-1).

a. Inherent Availability (A_i)

Inherent availability takes into account only items of systems design. Additionally, it assumes an ideal support environment and includes only active corrective maintenance time in calculation of downtime while excluding preventive maintenance time and servicing times as well as supply, administrative and personnel delays. Inherent availability is expressed in terms of its designed mean time between failures (MTBF) and its designed mean time to repair (or active repair time) (MTTR) given that it has failed:

$$A_i = \frac{MTBF}{(MTBF + MTTR)} = \frac{MTBF}{(MTBF + \overline{M}_{ct})} \tag{2.6}$$

where M_{ct} = mean corrective maintenance time.

b. Achieved Availability (A_a)

Achieved availability is calculated when preventive maintenance is included in the relationship. However, an ideal (no delay) support system is still assumed, which excludes Logistics Delay Time (LDT) and Administrative Delay Time (ADT):

$$A_a = \frac{MTBM}{MTBM + \overline{M}} \tag{2.7}$$

where M = mean active maintenance time (both preventive and corrective maintenance activities) and *MTBM* is the mean time between maintenance, both corrective and preventive.

c. Operational Availability (A_o)

Operational Availability is a function of the reliability and maintainability of the equipment and is a commonly used measure of weapon system readiness. It is the most desirable form of availability to be used in helping assess a system's potential under fielded conditions whereas achieved availability and inherent availability are primarily the concern of the developing organization in its interface with the contractor (DSMC, "Acquisition Logistics Guide", p. 10-4). Specifically, operational availability is the probability that a system, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon at any random time. Additionally, operational availability includes all of the sources of non-operable time, active and inactive to include supply and administrative delay times, corrective and

preventive maintenance, and personnel/maintenance technician delays. The value provides both the percentage of time that a system is in a mission capable status in the long-run and the percentage of weapon systems in mission capable status:

$$A_o = \frac{MTBM}{MTBM + MDT} = \frac{Number of\ MissionCapableSystems}{Totalnumber of\ systems} \tag{2.8}$$

where MDT = maintenance downtime, or the total elapsed time required to repair and restore a system to full operating status. Maintenance downtime (MDT) includes mean active maintenance (M), logistics delay time (LDT), and administrative delay time (ADT).

Despite which expression of availability used, it is obvious that reliability is a major driver in the numerator of these relationships.

6. Reliability Component Relationships

Overall system reliability is a function of the reliability of subsystems and components. With today's technology, systems performance may often be increased at the expense of increased complexity; the complexity usually being measured by the number of required components and parts. However, unless compensating measures are taken to improve the reliability of the components, system reliability will decrease. This is because if nothing else is changed, reliability decreases with each added component. In such cases of increased system complexity, reliability can only be maintained if component reliability is increased or if component redundancy is built into the system. However, each of these solutions, in turn, must be measured against incurred costs (Lewis, p. 3).

The decrease in reliability due to increased system complexity may be expressed in terms of the product rule. The reliability of the system is the product of reliabilities of the individual subcomponents. In other words, if the component failures are mutually independent in a series form, the reliability of the system with N nonredundant components is:

$$R = R_1 R_2 \ldots R_n \ldots R_N \tag{2.9}$$

As depicted, in a series network, all components must operate in a satisfactory manner if the system is to function properly. Connecting subsystems in a series tends to

decrease reliability, since the reliability of the entire system is equal to the product of the individual reliabilities of that system.

However, from a reliability perspective, system components can be integrated in parallel form, enabling system developers to increase system reliability through increased redundancy in the system. In a parallel network, a number of the same components are in parallel, and thus, all components must fail in order to cause total system failure. For a system with n identical components, the reliability expression for the system is:

$$R = 1 - (1 - R)^n \tag{2.10}$$

Parallel redundant networks are used primarily to improve system reliability (Blanchard, p. 45). Additionally, various levels of reliability can be achieved through the application of combining series and parallel networks. In fact, a combination of both types of systems is commonplace and almost unavoidable. Once systems engineers determine the reliability of individual components, overall system reliability can be empirically calculated. Ultimately, the true source of system reliability rests with the performance of individual components and subsystems (Chaudhary, p. 26).

7. Reliability Bathtub Curve

The reliability of a system and its components will fluctuate throughout their development, production life cycle, and operational usage. Additionally, product updates, system changes or modifications, and maintenance actions further affect the reliability of systems and their components. However, assuming a negative exponential distribution, the failure rate is relatively constant during the mature stages of a system life cycle as shown in Figure 2.1. It is during this relatively stable portion of the curve that the exponential failure law applies. However, when systems are initially operational, there are usually a higher number of failures mostly attributable to poor manufacturing techniques, poor quality control, poor workmanship, insufficient burn-in or break-in, improper installation, insufficient debugging, human error, and other causes. As a result, the initial failure rate is higher than anticipated before leveling off to the constant failure-rate region. Likewise, when a system reaches a certain age, it enters its wear-out life period where the failure rate once again increases (Kececioglu, p. 74). It should be noted that the curve would vary depending upon the type of system and its operational usage.

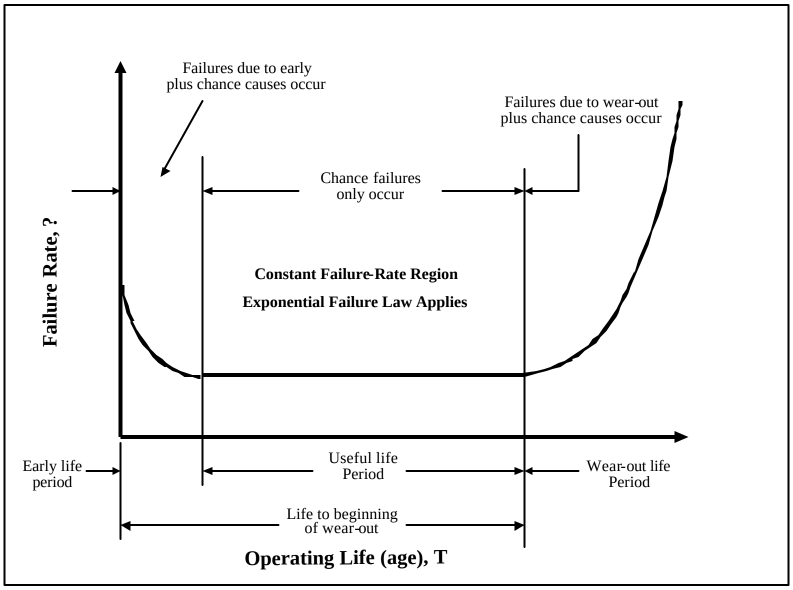

Figure 2.1. Reliability Bathtub Curve. (From: Kececioglu, p. 74)

Effective reliability programs require the assessment of reliability at key decision points along the growth curve. Data availability for making projections obviously increases as the program and its tests progress. For example, during the early life period, known as the infant mortality period, reliability estimates must be made on information obtained from stress calculations, proven component data from similar equipment, accelerated testing, and potential problem analysis, all of which are reliability analysis tools to be discussed later in this Chapter.

Ultimately, the actual reliability level of a system and its components, as well as the confidence in the estimated level, increases with the test program and its corresponding corrective actions. Attempts must be made to obtain the required times-to-failure and success-and-failure data in an effort to prepare a reliability bathtub curve, plotting the failure rate of a system versus its age. Such a curve enables the estimation of (a) the optimum break-in testing period and burn-in time, (b) the optimum warranty time and its cost, (c) the optimum preventive replacement time, and (d) the spares requirements (Kececioglu, “Reliability Engineering Handbook”, p. 37).

C. RELATIONSHIP BETWEEN RELIABILITY, LOGISTICS, LIFE CYCLE SUPPORT COSTS AND READINESS

Early materiel life cycle decisions during the acquisition process have a significant impact on future operational availability and life cycle cost of weapon systems. This is largely due to the fact that reliability characteristics that are inherent within the system design actually dictate the requirements for the subsequent maintenance and support of that system throughout its life cycle (Blanchard, p. 252). In addition to actual inherent reliability associated with system design, under- or over-estimations of the reliability of weapon systems in development dramatically and often adversely affect life cycle cost and operational availability as the reliability estimate provides the basis for initial life cycle supportability decisions.

Weapon systems must be designed to be supportable for the warfighter, capable of being maintained effectively and efficiently throughout their planned life cycles, ultimately enabling the warfighter to focus his efforts on his primary task of winning battles and providing him with equipment capable of doing so. Therefore, the DOD must remain focused on the goal of providing systems that maximize their operational availability (A_o) within the allocated life-cycle cost (LCC) of the program. When considering readiness and supportability objectives within budgetary constraints, system reliability emerges as the prominent life cycle cost and readiness driver for defense weapons systems. Thus, it is critical to consider the role of reliability in planning for integrated logistical support in the early stages of planning and design as well as throughout the entire acquisition process. However, before attempting to specify quantitative reliability requirements and considering managerial or procedural methods to improve reliability, one must be able to clearly establish the link between reliability, life cycle cost, and readiness.

1. Impact of Reliability on Operational Availability

The ability to successfully complete a mission is directly dependent on the weapon performing that mission without experiencing a mission critical failure. In other words, weapon system reliability directly affects the ability of the Marine Corps to perform its mission. With this in mind, it becomes clear that "reliability isn't everything, it is the only thing" (Eaton Email, 25 April 2001).

The following formula indicates that there is a definite direct relationship between reliability, maintainability, and readiness (A_o):

$$A_o = \frac{uptime}{uptime + dowtime} = \frac{MTBM}{MTBM + MDT} = \frac{\overbrace{OT + ST}^{UPTIME}}{\underbrace{OT + ST}_{UPTIME} + \underbrace{ALDT + CMT + PMT}_{DOWNTIME}} \quad (2.11)$$

where,

OT = Operating Time

ST = Standby Time

ALDT = Administrative and Logistics Down Time

CMT = Corrective Maintenance Time

PMT = Preventive Maintenance Time

As “uptime” or Mean Time Between Maintenance (MTBM) increases as a result of increased reliability, operational availability (or readiness) also increases (DSMC, “Program Managers Tool Kit”, p. 43).

2. Impact of Reliability on Life Cycle Costs

While equipment failure due to poor reliability can be catastrophic, leading to life or death implications, reliability of many products may be viewed primarily in economic terms. Much of the projected life-cycle cost for a given system can be greatly impacted by decisions made during the early stages of advanced planning and conceptual and preliminary design. Management and design decisions at this point can have a major impact on the activities and operations in all subsequent phases of the life cycle. Thus, it is critical to consider reliability and its affect on logistical support in the early stages of planning and design in an effort to avoid unplanned excessive O&S costs throughout a system’s life cycle and not postpone reliability considerations to a downstream activity. The need to look beyond short-term initial cost of procurement and acquisition and address system life-cycle cost is obvious, and experience has shown that logistics requirements can have a major impact on overall life-cycle cost (Blanchard, p. 4). Understanding that initial life cycle supportability requirements to include integrated logistics support is based on reliability estimates, it becomes clear that reliability needs to

be recognized as a significant factor throughout the life cycle while assuming a major role in research, design, production, and system performance during operational use. An increased focus on reliability can lead to reduced life cycle support costs, equating to increased funds available for recapitalization and modernization of forces. Likewise, because of its recognized importance, it is mandatory for all program managers with the Department of Defense to plan for and execute measures to ensure their program accounts for the user's RAM objectives (DoD 5000.2-R).

Along with the latest revision to the DoD 5000 series acquisition directives in October 2000, the Secretary of Defense issued a memorandum that outlined six major themes in the updated documents. One of the major themes is that, "The acquisition process must consider both performance requirements and fiscal constraints. Accordingly, cost must also be an independent variable in programmatic decisions." The theme, known as, Cost As an Independent Variable (CAIV), is an initiative intended to put focus on life-cycle costs by considering both performance requirements and fiscal constraints by making cost and performance trade offs. Over the past decade, the relative importance of LCC has greatly increased, and it is now mandatory for the major acquisition category programs. Additionally, many contemporary political issues dictate that the control of costs associated with procurement and life cycle management of weapon systems receive an unprecedented level of management attention (DSMC, "Acquisition Logistics Guide", p. 12-1).

The concept of CAIV must by utilized in establishing an effective acquisition strategy. Per DoD 5000.2-R, the acquisition strategy shall address methodologies "to acquire and operate affordable DoD systems by setting aggressive, achievable cost objectives and managing achievement of these objectives". A strategy that considers the total cost to the government over the entire cradle-to-grave cycle of the system is "necessary to provide balance and perspective to the program in consideration of the performance and schedule requirements to avoid suboptimization". In this regard, program managers primary focus should be on minimizing life cycle cost (DSMC, "Acquisition Strategy Guide", p. 2-12).

a. Background and Components of LCC

DOD TOC is comprised of costs to research, develop, acquire, own operate, and dispose of weapon and support systems, other equipment and real property, the costs to recruit, retain, separate and otherwise support military and civil ian personnel, and all other costs of business operations of the DOD. Defense Systems TOC is defined as Life Cycle Cost. LCC (per DoD 5000.4M) includes not only acquisition program direct costs, but also the indirect costs attributable to the acquisition program (i.e., costs that would not occur if the program did not exist). For example, indirect costs would include the infrastructure that plans, manages, and executes a program over its full life and common support items and systems.

For purposes of cost estimating, LCC is typically divided into research and development (R&D), procurement, operations and support (O&S), and disposal. Life Cycle Costs involves all costs associated with the system life cycle, to include the following:

- *Research and development (R & D) cost.* Those costs incurred from program initiation at the conceptual through the end of engineering and manufacturing development. R&D costs include the cost for feasibility studies, modeling, tradeoff analyses, engineering design, development, fabrication, assembly and test of prototype hardware and software, system test and evaluation, associated peculiar support equipment, and documentation.
- *Procurement cost.* Includes the costs associated with producing or procuring the prime hardware, support equipment, training, data, initial spares, and facilities.
- *Operation and support (O&S) cost.* Consists of all costs incurred by the DOD to field/deploy the system including personnel, consumable and reparable parts, fuel, shipping, and maintenance. Includes the cost of sustaining operation, personnel and maintenance support, spare/repair parts and related inventories, test and support equipment maintenance, transportation and handling, facilities, modifications and technical data changes, and so on.
- *System retirement or disposal cost.* Captures costs associated with deactivating or disposing of a materiel system at the end of its useful life. (DSMC, "Acquisition Logistics Guide", pp. 12-3 – 12-4).

As depicted by the categories listed above, life cycle cost of a weapon system begins with the determination of a mission requirement and continues through design, development, production, operation, support, and eventually the disposal and demilitarization of the system at the end of its useful life. It is widely accepted within the acquisition community, that the costs of operating and supporting a weapon system far exceed the actual procurement costs incurred through the design, development, and production of a new system. Although the percentage of life-cycle costs attributable to each element is not identical for all weapon systems, there is little variation across the range of various systems. The historical life-cycle cost percentage breakdown for major defense weapon systems is depicted in Figure 2.2 (OSD CAIG, “O&S Cost Estimating Guide”).

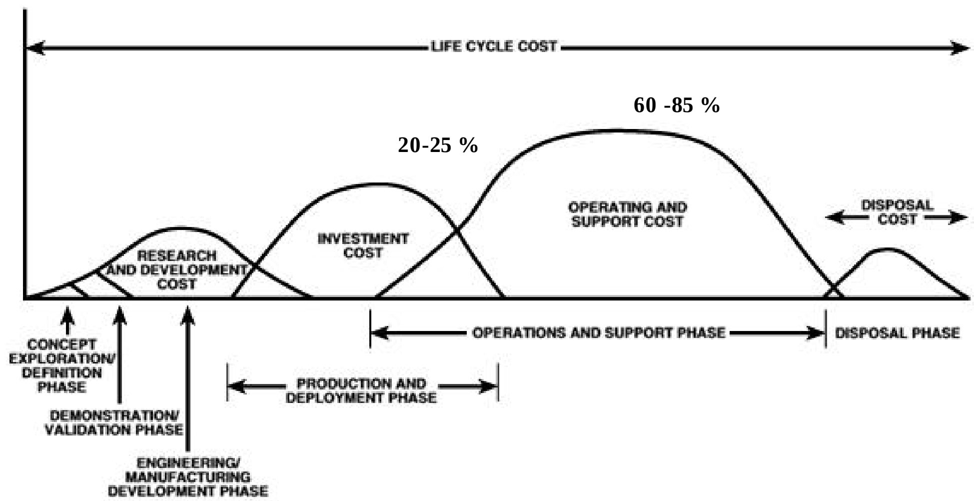

Figure 2.2. Weapon System Life Cycle Cost Breakdown.

While production may be viewed as the most costly portion of the program per unit of time, it actually only amounts to roughly 30% of the LCC. Based on these figures, it becomes readily apparent that the largest cost driver in the life of a system is the O&S phase. To further compound this figure, when today’s aging systems exceed their originally intended life expectancy, O&S costs can actually form 75-90% of a system’s LCC (Parker, p. 275). Understanding that an increasing portion of the defense

budget is being consumed by growing O&S expenditures, there has understandably been considerable effort to reduce such costs. Ultimately, the increase of funds available for recapitalization and modernization of legacy systems will result through the reduction of O&S funds.

In the past, total system cost has either not been obvious or has been somewhat ignored due to incentive and managerial issues, particularly those costs associated with operation and support. As previously discussed, a major portion of the projected life-cycle cost for a given system or product results from the consequences of decisions made during the early phases of program planning and system conceptual design. Referring back to Figure 2.2, while the greatest proportion of life cycle costs occur during the operation and support phase of a program, the greatest opportunity for influencing these costs occurs during the early phases of the program as shown in Figure 2.3.

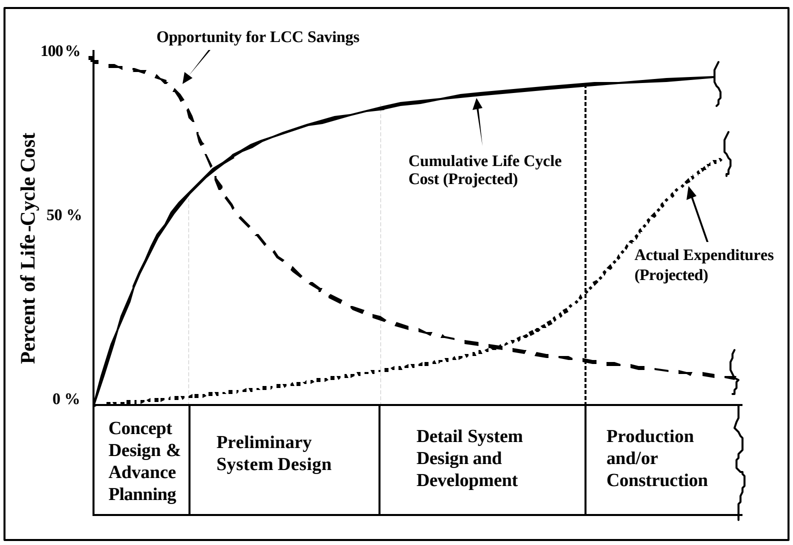

Figure 2.3. Commitment of Life-Cycle Cost. (From: Blanchard, p. 82)

The recent CAIV acquisition reform initiative is a way of developing life-cycle cost targets for the system to be acquired and constraining the system design trade-offs by the target cost of system ownership. Prior to the CAIV concept, the Design-to-

Cost approach (DTC) was very prominent within the acquisition community. However, the DTC approach had primarily concentrated on controlling system procurement costs, rather than life-cycle cost. As a result, DTC created the wrong incentives for former program management offices, resulting in programs that did not adequately address sustainment and life cycle cost consequences of early acquisition decisions.

b. Life Cycle Cost Analysis

Life cycle cost analysis is typically part of the supportability analysis, discussed later, and is conducted to address the total cost of a system and its supporting activities throughout its planned life cycle. Such an analysis includes the estimation of the system life cycle cost (design and development, production and/or construction, system utilization, maintenance and support, and retirement/disposal costs), high-cost contributors, cause-and-effect relationships, potential areas of risk, and identification of areas for improvement or cost reduction (Blanchard, p. 176). Due to the fact that much of the downstream cost is the consequence of design and management decisions made during the early stages of conceptual and preliminary design, the use of life cycle cost analysis is critical if a program management office is to assess whether or not the system can be operated and supported in an effective and efficient manner throughout its intended life cycle.

Many factors are involved with the estimation of life cycle costs. Specifically, reliability considerations, estimates, and the accuracy of such estimates play a significant role in LCC estimations. The fundamental objective of LCC reduction analysis is to identify the cost drivers that most significantly affect life cycle costs. Such analyses allow for trade off considerations with respect to different courses of action. During each phase of the acquisition cycle, engineers and managers provide prompt feedback regarding the costs of new or alternative designs or other economical solutions with respect to their effect on LCC forecasts. Likewise, engineers and managers must achieve a proper balance between acquisition decisions and costs and the resulting (predicted) operation and support costs. Figure 2.4 illustrates the design linkage with operation and support cost drivers (DSMC, "Designing Quality into Defense Systems", p. 41-42).

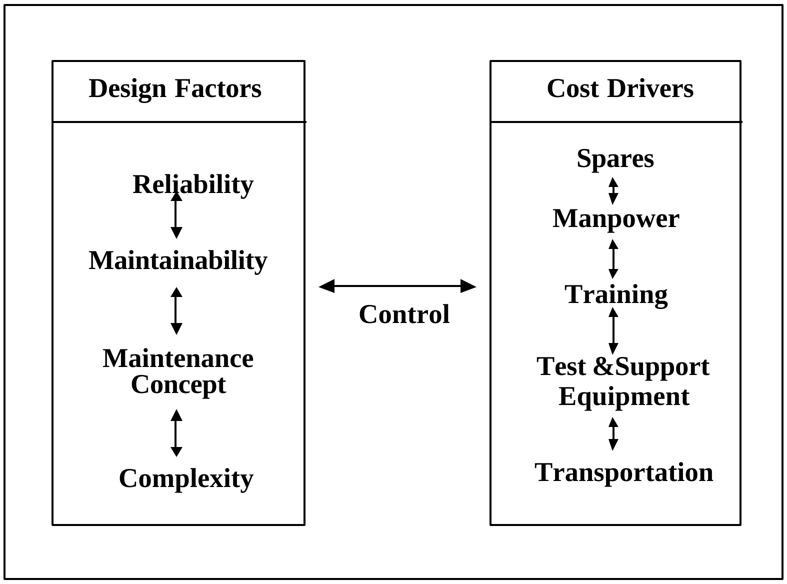

Figure 2.4. Design and Life Cycle Cost Linkage. (From: DSMC, "Designing Quality into Defense Systems", p. 42)

There are countless examples of how reliability improvements in both Government and industry have resulted in substantial cost reductions. It is well know throughout the current acquisition community that initial investments in the design, development, and production of reliable weapon systems can have significant impacts on reducing O&S costs and ultimately LCC. Such an example is the DoD's Minuteman I missile system which implemented a reliability improvement study that eventually led to a 30% reduction in the failure rate. The cost-effectiveness analysis revealed a return of eight dollars for every dollar invested in reliability improvement. The net savings over a ten-year period was expected to be $160,000,000 (Kececioglu, p. 23). Another example of the potential cost savings can be found with the F-105 weapon system, which, by way of implementing a reliability improvement program, increased system reliability from .7263 to .8986. While the reliability program nonrecurring costs were estimated at $25,500,000, the annual savings in maintenance costs were estimated at $54,000,000 (Kececioglu, p. 24). It is clear that while upfront investments in reliability may increase

initial procurement costs, the significant savings resulting from the potential reductions in O&S and LCC quickly outweigh any upfront costs.

c. Break Even Analysis

A program must consider cost during reliability and maintainability design balancing activities. Fortunately, Life Cycle Cost models are available and often used as a vehicle by which estimates for operation, performance, reliability and maintainability, and cost are traded off to obtain "design to" target goals which collectively represent a balanced design. For the purpose of considering cost trade-offs, additional relationships are developed which define how cost changes as reliability and maintainability is varied from a baseline. Specifically, as a system is made more reliable, the operating cost should decrease since there are fewer failures to repair. At the same time, it is anticipated that acquisition cost (development and production) will increase to attain higher reliability in the system (DSMC, "Designing Quality into . . .", p. 11).

As discussed, improvements in system reliability, to a feasible extent, dramatically decrease system LCC. However, increasing system reliability beyond feasible technological levels may require an enormous amount of resources to be consumed during research and development (R&D) to the point that the cost savings from improved reliability may not offset such costs, resulting in less than optimal LCC. The theoretical relationship between system reliability and LCC is depicted in Figure 2.5.

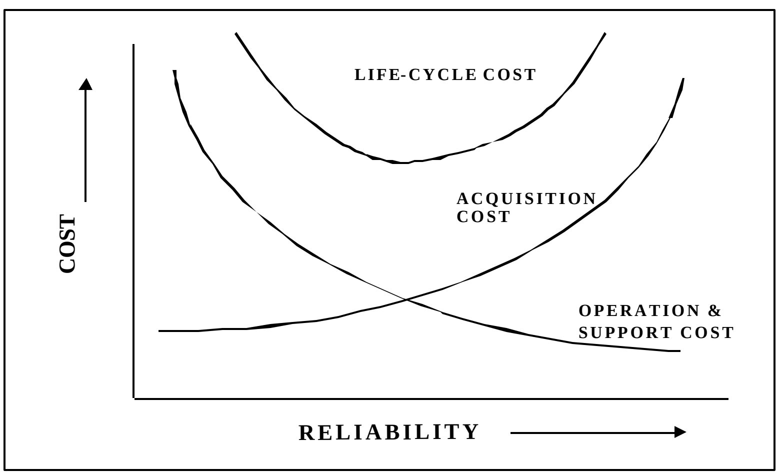

Figure 2.5. Reliability and LCC Tradeoff.

For proper economic analysis, one must consider the costs associated with the entire life cycle of a system, evaluating the trade-off between increased early investments in reliability improvement and the resulting future cost savings. When comparing alternatives, a program management office must consider both the aspects of cost effectiveness and the point in time where one alternative becomes more cost-effective than another alternative. A break-even analysis is an approach where the cumulative costs for two or more investment alternatives (or programs) are estimated, projected, and compared with respect to time. In the event that the break-even point is realistic in terms of expected system life, then it may cost-effective to consider the increased early investment during Research and Development phases in order to achieve higher system reliability. Figure 2.6 provides a comparison of two alternatives where it appears that the increased investment during R&D results in a more cost-effective option in the long run.

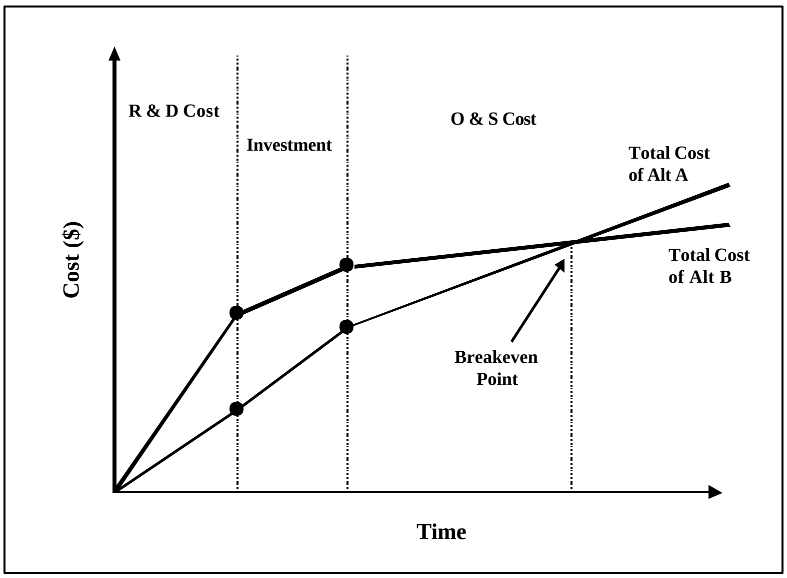

Figure 2.6. Break-Even Analysis. (From: Blanchard, p. 89)

d. Cost Effectiveness

It is important to understand that when deciding upon the optimal level of reliability to be designed, manufactured, and maintained into a product, it is not

necessarily the point at which the cost to own, operate, and maintain the product for its desired life is minimum. Rather, the primary objective should be to develop a system that is most cost-effective, within the constraints of operational and maintenance requirements. In other words, the acquisition community should not aim to strictly minimize LCC, and instead, should consider cost effectiveness as it relates to the measure of a system in terms of mission fulfillment (system effectiveness) and total life cycle costs (Blanchard, p. 34). Cost effectiveness involves a cost-benefit analysis factor employed for decision-making purposes.

When considering cost effectiveness, the aspects of effectiveness must be quantified and depend upon the specific mission or system characteristic that a program desires to specify and measure. While measuring effectiveness, one must consider:

- *System performance and physical parameters:* capacity, delivery rate, power output, range, accuracy, volume, speed, weight, etc.
- *System operational and support factors:* availability, dependability, capability, operational readiness, reliability, maintainability, etc.
- *Total life-cycle cost:* research and development, production/construction cost, operation and maintenance cost, retirement and disposal cost (Blanchard, p. 83)

In order to achieve a desirable cost effectiveness, a relationships must be established between performance and operational parameters and cost. Figure 2.7 illustrates an example of the relationship between reliability (MTBF) and total life cycle cost, where the objective is to design a design a weapon system that meets a specified reliability level within a given budget level and yet be most cost-effective. System design characteristics are evaluated in terms of reliability and cost, and as a result, design changes are recommended in an effort to achieve the point on the curve near the minimum cost (Blanchard, p. 88).

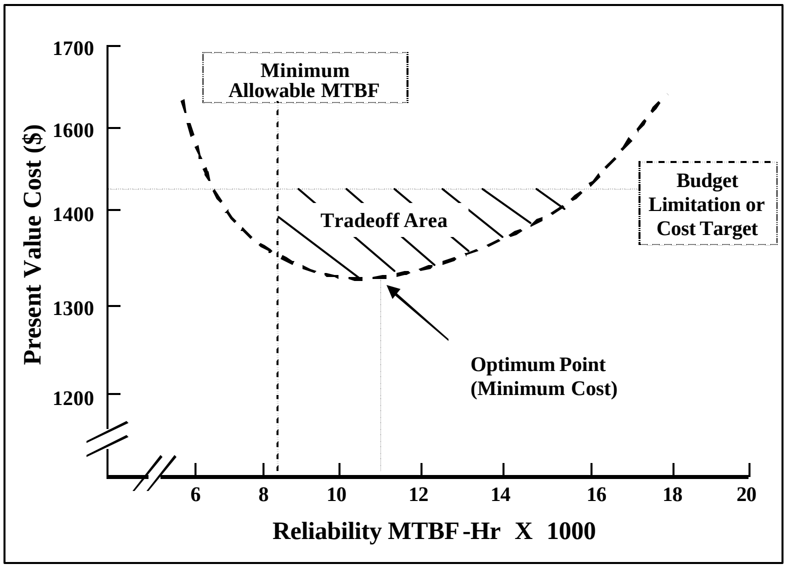

Figure 2.7. Reliability versus Cost. (From: Blanchard, p. 88)

There is a significant increase in costs associated with achieving higher levels of reliability. In fact, the marginal increase in reliability bec omes increasingly smaller and the marginal cost becomes increasingly larger as developers attempt to maximize the level of reliability. In other words, in may be relatively inexpensive to increase reliability from 50% to 70% while it may be far more costly to increase system reliability from 98% to 99%. Therefore, it is not typically optimal to strive for 100% reliability. Figure 2.8 illustrates the diminishing marginal gain associated with achieving higher levels of reliability.

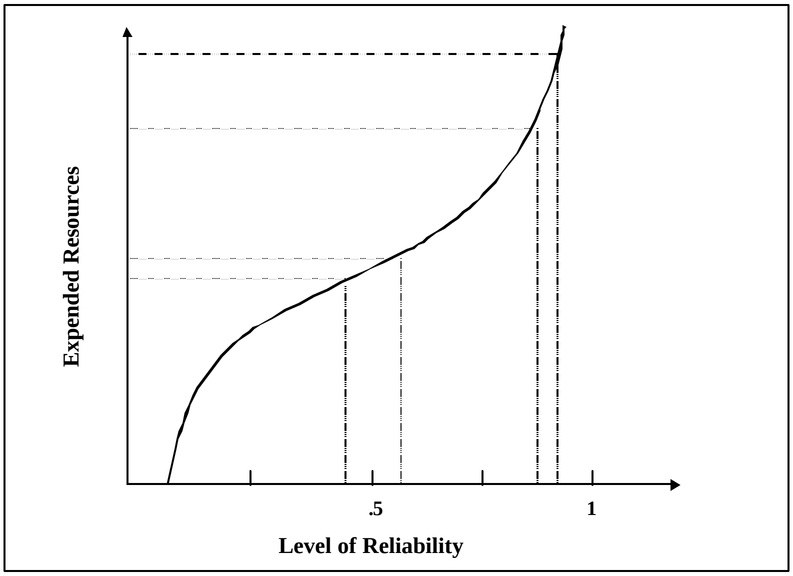

Figure 2.8. Reliability S-Curve. (NPS Logistics Engineering Class Notes)

e. Life Cycle Cost Models

Numerous commercial life cycle cost models have been developed in an effort to help Program Managers structure and analyze large amounts of data used to support major LCC decisions. One of the major advantages of the LCC models is their ability to provide early input to the front-end design analysis stage of the Concurrent Engineering (CE) and Logistic Supportability (LS) processes. Basically, the models available are database managers that have the capability, to varying degrees, to import, modify, analyze, integrate, and manage large amounts of data from many different sources. Reports can be generated that display or project the overall effects and results of program decisions on existing or alternative system designs, including risks thereof while storing a baseline of program decisions. The life cycle cost models provide a design and support system tradeoff with sensitivity and comparative analyses, providing the flexibility of rapidly assessing the reliability, LCC and logistic supportability impacts of various equipment configurations and other design supportability options (Sterling, "Analysis of LCC Models for DoD"). Some of the life cycle cost models available to Program Management Offices include but are not limited to EDCAS, ACEIT, FLEX+,

CASA, and the COCOMO model, all of which offer varying degrees of advantages as well as disadvantages relative to the others. The specific application of the models will not be discussed in this text as it is beyond the scope of the thesis.

D. SUPPORTABILITY ANALYSIS

Supportability analyses are a wide range of related analyses that should be conducted within the systems engineering process. Specifically, supportability analysis (SA) is

> . . . an iterative analytical process by which the logistic support necessary for a new (or modified) system is identified and evaluated. The SA constitutes the application of selected quantitative methods to (1) aid in the initial determination and establishment of supportability criteria as an input to design; (2) aid in the evaluation of various design alternatives; (3) aid in the identification, provisioning, and procurement of the various elements of maintenance and support; and (4) aid in the final assessment of the system support infrastructure throughout the utilization phase (Blanchard, p. 24).

Reliability characteristics inherent within the system design actually dictate the requirements for the subsequent maintenance and support of that system throughout its lifecycle, and thus, program offices must establish the appropriate logistic support requirements in the early stages of conceptual design (Blanchard, p. 252). However, in addition to actual inherent reliability associated with system design, under- or over-estimations of the reliability of weapon systems in development can dramatically, and often adversely, affect life cycle cost and operational availability as the reliability estimate provides the basis for initial life cycle supportability decisions. Therefore, accurate reliability predictions and thorough analyses are required as an integral input to the supportability analysis.

The supportability analysis includes two major areas of focus. The first is the accomplishment of design trade-off studies, level of repair analyses, life-cycle cost analyses, and related activities directed toward the objective of *designing for supportability.* The second area of focus involves the evaluations of the system design configuration, as it exists at the time, with the objective of defining logistic support resource requirements (i.e., spare/repair parts, test and support equipment, number of maintenance personnel, level of personnel training, etc.). With the identification of

specific logistics requirements identified, the provisioning, procurement, and acquisition process commences (Blanchard, p. 355). Ultimately, the supportability analysis leads to a database that assists in identifying the specific requirements leading to the development of the maintenance and support infrastructure. The overall intent is to design or develop a system that will meet the specified operational requirements in an effective and efficient manner by maximizing system effectiveness while minimizing life cycle cost.

E. RELIABILITY ANALYSIS AND AVAILABLE TOOLS

The reliability analyses can be used to define the quantitative parameters for a system, subsystem, or component, and it is often expressed in number of failures in a given set period of time, set number of cycles, or a set number of operations (i.e., rounds fired, number of starts, etc). As engineering data become available, reliability prediction serves as a check on the design in relation to the system requirement, indicating areas of incompatibility that may need evaluated for design improvement. As previously discussed, the level of reliability achieved in fielded systems directly affects operational availability and sustainment requirements. Therefore, successful system designs require that component and system reliability be predictable. This requires that a reliability program be established to assess the reliability of system components. Accurate data is crucial in establishing reliability information, and the more data available, the greater the confidence that can be expressed in the estimated or predicted reliability level.

During logistical support planning, the Marine Corps is forced to rely upon estimates, and unfortunately, reliability data is often difficult to obtain, as it is acquired through observing the failure of products and their components. This requires life testing, in which a number of items are tested until a significant number of failures occur. However, such tests are often very expensive, since they are destructive, and to obtain meaningful statistics, substantial numbers of the system or subsystem must fail. The tests are also time consuming, since few unbiased acceleration methods are available to greatly compress the time to failure, the test time may be comparable or longer than the normal product life. Reliability data is also collected from field failures once a product is put into operational use. However, this is a lagging indicator and is not nearly as useful as results obtained earlier in the development process (Lewis, p. 49). Additionally, it is important that reliability be considered in the concept and design process because

identifying and correcting related problems in later stages of the life cycle has an adverse cost leverage as shown in Figure 2.9.

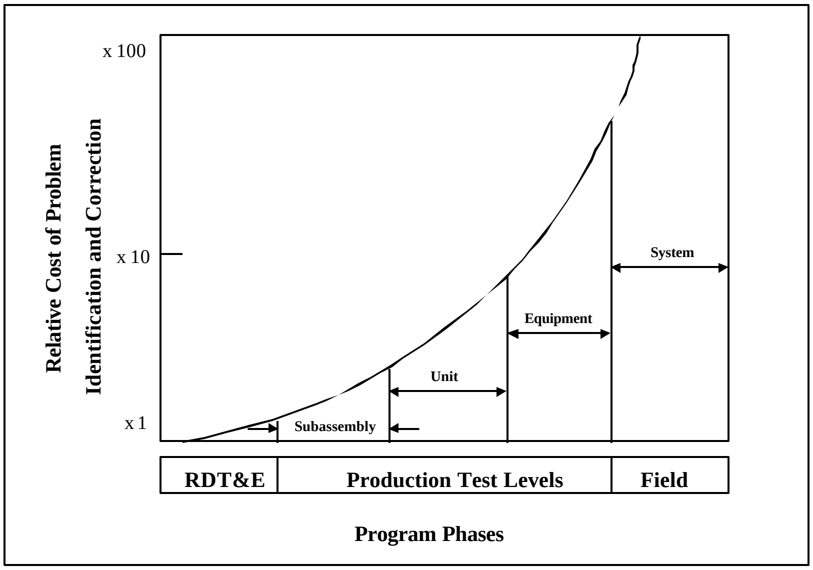

Figure 2.9. Relative Costs of Problem Correction versus Program Phase. (DSMC, "Designing Quality into . . ." p. 30)

Multiple potential opportunities are present throughout the acquisition life cycle to address reliability. Beginning with the initial requirements generation, through each iteration of the systems engineering process, and ultimately during post-production, reliability must be planned for, monitored, accessed, and improved during the maturation of a weapon system (Ryan, p. 1). The program's application of special reliability tasks enhances the capability of satisfying the warfighter or user's needs. However, reliability tasks must be fully integrated into the total technical program and be performed concurrent with other engineering tasks to ensure reliability is designed-in before design maturity reaches a stage when engineering changes become costly to implement (Reliability, Maintainability, and Supportability Guidebook, SAE International, p. 70). While the list of key reliability tasks, below, serve slightly different purposes, they are applicable to varying equipment types, and range in depth, scope, and complexity of the task, if properly conducted, all, in some capacity, can provide a valuable contribution to

the design and development of a system with respect to reliability performance. These tasks must be tailored to fit the particular program need. Furthermore, the tasks listed are only those with the widest acceptance and application within program management and are not all-inclusive.

- Reliability Requirements Definition
- Reliability Program Plan
- Reliability Design Standards/Guides/Checklists
- Environmental Criteria
- Reliability Modeling
- Reliability Allocation and Apportionment
- Reliability Prediction
- Subcontractor/Supplier Monitoring and Control
- Reliability Design Evaluation
- Failure Modes Effects and Criticality Analysis (FMECAS)
- Process Failure Modes and Effects Analysis (PFMEA)
- Reliability Development/Growth Test (RD/GT)
- Weibull Analysis
- Failure Reporting, Analysis, and Corrective Action (FRACAS)
- Software Reliability Assessment
- Parts Control Program
- Environmental Stress Screening (ESS)
- Reliability Qualification Test (RQT) Program
- Probabilistic Design Assessment for Reliability
- Fault Tree Analysis
- Part Stress Derating
- Worst Case Circuit Analysis

The integrated analyses can include any number of tools, practices, or techniques to realize reliability and supportability characteristics. The tasks above, or some combination of them, should be selectively applied to each program based on the program's life cycle, system complexity and type, technology advancement, and schedule and cost constraints. If the selected reliability tasks are appropriately tailored for scope

and depth and adequately integrated with other program tasks, an effective reliability program will result ((Reliability, Maintainability, and Supportability Guidebook, SAE International, p. 71).

F. PROGRAM MANAGER/WEAPON SYSTEM MANAGEMENT IMPLEMENTATION

Program Management/Weapon Systems Management (PM/WSM) is defined as "the planning, organizing, acquisition, controlling, sustainment, and disposal of weapon systems and secondary items in support of validated Marine Corps requirements," while Supply Chain Management is defined as "the planning, organizing, and controlling of supply chain activities for the Marine Crops wholesale and retail supply business to maintain and support assigned principle end items and secondary items" (PM/WSM "Activities Definitions"). Under the recent PM/WSM initiative, traditional roles, responsibilities, resources, and billets of Marine Corps Systems Command (MARCORSYSCOM) and Marine Corps Logistics Base (MARCORLOGBASES) were realigned to optimize Life Cycle Management of weapon systems. The initiative was established to "clearly delineate authority, responsibility, and accountability of managers and organizations" (Williams, PM/WSM Slide Show dtd 17 Jan 01).

Prior to the Program Manager/Weapon System Manager Implementation efforts, a major weapon system was procured and fielded at MARCORSYSCOM and was passed on to MARCORLOGBASES for Sutainment/Life Cycle Management. As a result of this disjointed process, major weapon systems entered the Fleet and encountered severe readiness and supportability problems (MARCORSYSCOM Study Plan "Sustainment Consequences . . .", p. 1). It has been argued that prior to the implementation of PM/WSM, the incentives in place for program managers caused them to focus on short-term program objectives that they were evaluated on such as procurement cost, schedule, and performance. Additionally, few if any, incentives were in place that encouraged program mangers to analyze long-term sustainment and life cycle cost consequences of their early acquisition decisions. However, under the realignment of responsibilities within Materiel Command (MATCOM), LOGBASES, and MARCORSYSCOM, Marine Corps Systems Command became responsible for the availability of equipment through the entire materiel life cycle. As a result, the decisions made early in the life cycle of a

system, that often have a tremendous impact on availability and sustainment, will directly impact the program management offices throughout the life span of the respective weapon systems.

G. CHAPTER SUMMARY

This chapter established the definite relationships between reliability, logistics, life-cycle support costs, and operational availability. In doing so, the researcher illustrated the fact that the reliability of a weapon system directly impacts the operational availability and the life cycle cost of the system, making it of fundamental importance to PM, logisticians, and warfighters alike. Appropriately, the core of logistical support planning focuses on reliability, in an attempt to ensure that warfighters are provided with capable, supportable, and cost effective weapon systems that enable them to successfully complete the mission on the battlefield.

Chapter III will provide an overview of the acquisition process while providing specific reference to opportunities within systems' life cycles for program managers to address reliability.

III. BACKGROUND AND OVERVIEW OF RELIABILITY WITHIN THE ACQUISITION PROCESS

> Reducing the cost to acquire and operate the department's equipment while maintaining a high level of performance for the user is my highest priority. - Under Secretary of Defense for Acquisition and Technology memorandum dated 04 December 1995

A. INTRODUCTION

One of the first major steps in the development of reliability focus in DoD acquisitions came in July 1980, when the DoD indicated an emphasis on reliability and maintainability by publishing a policy directive on the subject in the form of DoDD 5000.40. Until recently, there has been a lack of management emphasis on the support engineering disciplines such as reliability, and thus, the timely application of engineering techniques had not always been practiced. As a result, the efforts were not as supportable and cost effective as they could have been. Today, with the high level of TOC interest in the DoD, the management attention and interest is present, and as a result, we continue to make advancements in the way of reliability-focused acquisitions (Reliability, Maintainability, and Supportability Guidebook, SAE, p. 64).

This chapter provides the reader with background information on the defense acquisition process and serves to establish an understanding of general opportunities for reliability management within the process. First, an examination of current DoD and Marine Corps policies, regulations, and guidance is provided to establish the basis within which the acquisition community must operate to manage reliability within a program. Next, an overview of the acquisition process is provided, highlighting opportunities for reliability management throughout the process. Finally, the chapter will conclude by examining the existing roles, metrics, and incentives that guide the various organizations and individuals involved in the acquisition process.

B. DOD AND MARINE CORPS POLICIES, REGULATIONS, AND GUIDANCE ON RELIABILITY

Past and present Administrations and Congresses have instituted many initiatives to improve the acquisition of defense systems. In particular, the publication of the DoD 5000 Series of Directives in February 1991 resulted from the culmination of a

cooperative effort within the DoD to streamline policy by standardizing acquisition procedures. As a result, all acquisition tasks that were common among the service components were combined into the top-level policy, resulting in the cancellation of 65 other directives. The Department of the Navy implemented the DoD directives in SECNAVINST 5000.2A in December 1992, resulting in the cancellation of 39 additional directives. The Marine Corps implementation of the SECNAV policy in May 1994 resulted in the cancellation of 14 additional policy directives. "The resulting product of these three efforts is a single policy source outlining *broad* acquisition procedures for Marine Corps acquisition programs" (USMC PM Acquisition Procedures Handbook, p. 1-1)

Additionally, 1996 was a noteworthy year for acquisition policy changes. Defense policies now included acquisition streamlining, integrated product development, performance specifications, and the prohibition of most military specifications and standards. The 15 March 1996 reissuance of DoDD 5000.1 and DoD 5000.2-R (later with change 1 of 13 December 1996) promulgated these policy changes in directive format. The major focus of the new policies are teamwork (IPTs), teamwork with industry, tailoring empowerment, only performing value-adding tasks, employing Cost As an independent Variable (CAIV), a preference for commercial items, and use of best practices (DSMC, "Acquisition Logistics Guide", p. 1-2).

There are many sources of reliability guidance to assist program offices with achieving reliability requirements, a few of which are mandatory while others are discretionary or even cancelled. In fact, upon searching the Defense Acquisition Deskbook website for DoD (discretionary or mandatory) documents containing the word "reliability," 213 documents were located. Such policy, regulations, and guidance have been established to emphasize the importance of reliability and to ensure that the acquisition community is striving toward improved reliability techniques. As previously mentioned, much of the guidance is very broad scoped, providing little detail as to specific reliability actions to be taken in the acquisition process. Additionally, the amount of mandatory guidance is minimal and has further decreased in recent years due to acquisition reform initiatives. This section serves to provide a general overview of some of the sources of guidance as well as the nature of the guidance.

1. Mandatory Guidance

DoD 5000.2-R, Mandatory Procedures for Major Defense Acquisition Programs, states that as part of the acquisition strategy for a given program, program Managers shall develop and document a support strategy for life-cycle sustainment and continuous improvement of product affordability, *reliability*, and supportability, while sustaining readiness. RAM activities addressed in DoD 5000.2-R are summarized below:

- The PM shall establish RAM activities early in the acquisition cycle
- The PM shall develop RAM system requirements based on the Operational Requirements Document (ORD) and Total Ownership Cost (TOC) considerations, and then state them in quantifiable, operational terms that are measurable during development and operational testing
- Reliability requirements shall address *mission reliability* and *logistics reliability*
- Availability requirements shall address the readiness of the system
- Maintainability requirements shall address servicing, preventive, and corrective maintenance
- The PM shall plan and execute RAM design, manufacturing development, and test activities so that the system elements, including software, used to demonstrate system performance before the production decision reflect the mature design (DoD 5000.2-R)

DoD 5000.1 is another source of mandatory guidance which directs that:

> Acquisition program managers shall focus on logistics considerations early in the design process to ensure that they deliver reliable systems that can be cost-effectively support and provide users with the necessary support infrastructure to meet peacetime and wartime readiness requirements (DoD 5000.1)

Lastly, SECNAVINST 5000.2B, Section 4.3.6 – Reliability, Maintainability, and Availability – serves to interleave the higher-level policy.

2. Discretionary Guidance

In addition to the limited mandatory guidance on reliability, there is an abundance of discretionary guidance, consisting mostly of Military Handbooks. Such discretionary guidance most typically emphasizes integration of reliability into the design, manufacturing, and support process while providing *recommended* tools and procedures for doing so. It is important to note that because the handbooks serve as guidance only,

they cannot be cited as requirements. Due to amount of existing documents, only the most relevant sources will be identified in this section.

Military Handbook (MIL-HDBK)-781A, *Handbook for Reliability Test Methods, Plans, and Environments for Engineering, Development Qualification, and Production*, provides a list of reliability test methods, reliability test plans, and envir onmental profile data that can be used as a guide when testing systems for contractual reliability requirements during developmental testing.

MIL-HDBK-189, *Reliability Growth Modeling*, outlines reliability growth concepts and methodologies for management of reliability growth during the developmental stage by presenting fundamental concepts followed by details for concept implementation.

MIL-HDBK-502, *Acquisition Logistics*, offers guidance on acquisition logistics as an integral part of the systems engineering process, to include technical and management activities associated with the design, development, test, production, fielding, sustainment, and improvement modifications. Additionally, the handbook offers methods to "identify, consider, and trade-off support considerations with other system cost, schedule, and performance elements to arrive at an optimum balance of system requirements that meet the user's operational and readiness requirements" (MIL-HDBK-502, Section 4).

The "US Marine Corps Program Managers Acquisition Procedures Handbook" implements DoD, DON, and Marine Corps directives on Defense Systems Acquisition. Additionally, the handbook serves as a "summation of Marine Corps and, if appropriate, MARCORSYSCOM philosophy and policy regarding selected acquisition subject areas" (USMC PM Acquisition Procedures Handbook, p. ii). However, the handbook offers minimal guidance concerning reliability related actions to be taken during the respective phases of the acquisition process.

Lastly, the DoD Defense Acquisition University (DAU) has published a series of guidebooks that are utilized during their courses of acquisitions instruction at Fort Belvoir, Virginia. While designed to be technical management educational guides written from a DoD perspective, the guidebooks reflect the latest DoD acquisition policies and procedures as described in the 5000 series.

DoD- and Marine Corps-specific policy, regulation, and guidance on reliability exist to establish the basis within which the acquisition community should operate to manage reliability within a program. While there is an abundance of DOD documentation concerning reliability within the acquisition process, most is discretionary with little mandatory guidance and procedures on the subject. Additionally, what is in print is often very vague in nature and provides little specific guidance to the Program Mangers.

C. OVERVIEW OF THE ACQUISITION PROCESS

The Program Manager must consider reliability and other acquisition logistics management activities throughout the system development to ensure the design and acquisition of cost-effective, supportable systems and to ensure that these systems are provided to the warfighter with the necessary support infrastructure for achieving the user's peacetime and wartime readiness requirements (DSMC, "Acquisition Logistics Guide", p. 3-11). Consequently, logistics requirements must be initially planned from the beginning, and subsequently into the system design process. Reliability tasks must be fully integrated into the program and be performed concurrent with other engineering tasks to insure reliability is designed-in before design maturity reaches a stage when changes become costly to implement. In the past, the emphasis on delivering capability (performance) in a timely manner (schedule) within procurement cost objectives has often overridden reliability and total ownership cost considerations. Likewise, logistics has been considered as a "bill to be paid later," and thus, DoD often struggles to efficiently and effectively maintain its existing mature weapon systems on today's battlefields.

In the defense sector, there has been a recent emphasis on early logistical planning during the acquisition process that has evolved through the concept of *integrated logistic support* (ILC), defined as a:

> Disciplined, unified, and iterative approach to the management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design, and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost. (DSMC, "Integrated Logistics Support Guide")

As a result of the recent focus on post deployment logistical supportability, there has been an increased emphasis on the early opportunities for addressing reliability within weapon systems acquisition. Initially, the Requirements Generation Process can serve as a primary tool for the Marine Corps to document quantifiable system reliability requirements in the Operational Requirements Document (ORD) in the form of Key Performance Parameters (KPP). The reliability requirements can be used in source selection as DoD converts specific performance specifications into contractual terms, which should perhaps include an inherent reliability goal. The Systems Engineering Process allows the contractor to build to required reliability performance specifications. Once contractors submit their reliability estimates, program planning and organizational management can emphasize an independent and rigorous reliability testing process throughout the development phase in order to demonstrate the required reliability performance levels to ensure the system will operate in the field as intended. While not an upfront opportunity, comparison and assessment of achieved field reliability to contractor reliability estimates could be conducted throughout weapon system maturation to ensure attainment of system reliability as planned.

The subsequent sections will provide an overview of the participants involved in the acquisition process, a summary of the process itself, and the opportunities to address reliability throughout the process.

1. Organizations and Participants in the Marine Corps Acquisition Process

Weapons systems acquisition is a very complex process, involving many different participants at varying levels. This section, a summation taken from the "USMC Program Managers Acquisition Procedures Handbook," provides an overview of the organizations and participants involved as well as a brief summary of their respective roles.

Before proceeding, it is important to note that the organizational chain of command is not the same as the systems acquisition chain and that certain levels are responsible for requirements while others are responsible for implementing those requirements.

The chain of authority for Marine Corps systems acquisition starts at the Department of Defense level where the responsibility for acquisition policy and major program decision authority has been placed with the Under Secretary of Defense, Acquisition, Technology, and Logistics (USD, (AT&L)). The position of USD (AT&L) is subordinate only to the Secretary and Deputy Secretary of Defense. In the systems acquisition hierarchy, the USD (AT&L) is the Defense Acquisition Executive (DAE), acting as the ultimate program decision authority on certain major programs preparing to move from one Milestone to the next.

Immediately below the USD (AT&L) in the systems acquisition hierarchy is the position of the Assistant Secretary of the Navy, Research, Development, and Acquisition (ASN, RDA). The ASN (RDA) performs the same role for the Secretary of the Navy that the USD (AT&L) does for the Secretary of Defense. ASN (RDA) is the sole decision authority within the Department of the Navy (DoN) for major Navy/Marine Corps programs, and is responsible for Navy acquisition policy. ASN(RDA) also serves as the Component Acquisition Executive (CAE) for the Navy, and is referred to as the Navy Acquisition Executive (NAE).

The next position in the Marine Corps acquisition hierarchy is the Commandant of the Marine Corps (CMC). The CMC is responsible for determining requirements and ensuring the resources (funding and people) for those requirements. However, the CMC is not directly involved in the program decision process. Instead, the CMC appoints a Milestone Decision Authority (MDA) to act in his behalf in the acquisition decision/policy process, similar to the roles performed by the NAE and USD (AT&L). The Commander, Marine Corps Systems Command (COMMARCORSYSCOM) performs the MDA role for the Marine Corps. Before proceeding, we must distinguish between Marine Corps Systems Command and the Marine Corps Combat Development Command (MCCDC).

There are two major functions involved in systems acquisition – requirements determination and acquisition. As previously discussed, the CMC's role at the top level is primarily with requirements determination. However, the Commanding General, MCCDC acts as the CMC's agent in this process. Part of MCCDC's overall mission is to

translate deficiencies and desired capabilities into operational requirements. Meanwhile, the mission of MARCORSYSCOM, simply stated, is to take a validated requirement and turn it into reality, in the form of warfighting weapon systems and equipment. The CG, MCCDC acts as the Commandant's agent in developing requirements while the Commander, MARCORSYSCOM acts as his agent in acquiring the systems that fulfill those requirements. Clear boundaries between requirements determination (CG, MCCDC) and acquisition (COMMARCORSYSCOM) exist to effectively translate operational needs into stable and affordable acquisition programs.

The Program Managers (PMs) are responsible for directing the efforts of acquiring the systems to fulfill the validated requirements. They are responsible for taking the requirement from concept to an operational system. According to the "USMC PM Acquisition Procedures Handbook," in broad terms, the Program Managers have three major responsibilities: "Cost, Schedule, and Performance." It should be noted that the handbook mentions "logistical supportability" as a part of performance criteria for which program managers are responsible while indicating that Integrated Logistics Support is the process by which to achieve such criteria (USMC PM Acquisition Procedures Handbook, Chapter 1).

With the inclusion of the PM, we have completed the streamlined program decision relationship in the acquisition hierarchy: PM to CMDR, MARCORSYSCOM, to CAE (NAE), to DAE. Figure 3.1 generically depicts the Marine Corps participants in the acquisition process, from generation of the requirement and program initiation, to fielding and post-deployment support.

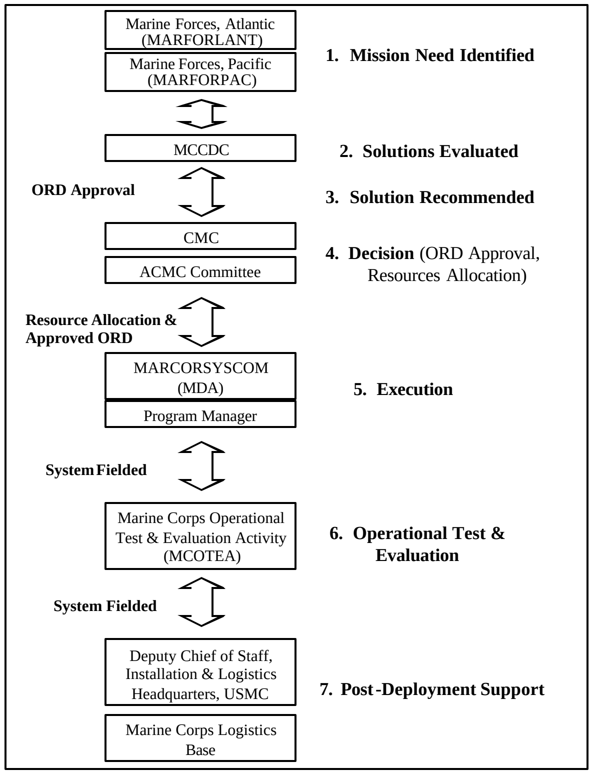

Figure 3.1. Participants in the Acquisition Process. (From: USMC PM Acquisition Procedures Hnbk, p. 1-14)

2. Acquisition Phases and Milestones

Along with the recent changes to the DoD Directive 5000 series, a new DoD Systems Acquisition Process model was created which was intended to deliver advance technology to the warfighters faster, reduce total ownership costs and improve affordability, and deploy interoperable and supportable systems. Some professionals may argue that there is little significant difference between the old and new models depicted in Figure 3.2 aside from the stages and milestones renamed. However, others point out that the new model integrates testing and evaluation throughout the system; allows for "evolutionary developments" based on time-phased (ORD) requirements; offers multiple process paths or entry points into the process depending on conceptual and technical maturity of the existing system; separates technology development from system

integration; ensures "entrance criteria" before entering the next phase which serves as a gate for the Milestone Decision Authority to decide if the program should continue; includes operation, support, and disposal as part of the acquisition process; and requires full funding at system development vice program definition, creating more competition between competitors. Despite which model a program is guided by, DoD controls the acquisition process through a series of tailorable Milestones and Phases that serve as decision points and goals to be achieved. Additionally, phases help focus the effort and define the necessary activities for effective management. However, due to the dynamic nature of DoD acquisitions, Program Management must remain flexible (NPS MN3331 Class Notes, "Principles of Systems Acquisition and Program Management").

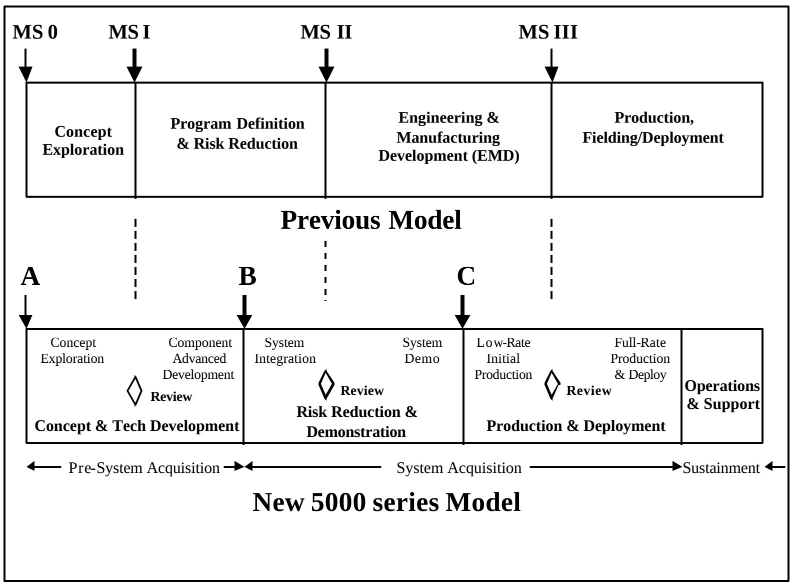

Figure 3.2. The System Acquisition Models.

Throughout the remainder of this thesis, future references of the phases and milestones most often cite the previous model due to the fact that the systems examined in this study were procured under such processes.

a. Acquisition Program Baseline (APB)

Each program has an APB that defines the cost, schedule, performance, and supportability measures that it must meet, with thresholds and objectives defined that

serve as boundary parameters within which the PMs operate. The APB serves as a "contract" of sorts between the PM and the MDA. Reliability related parameters such as MTBF, A_o, and MTBM exist for each program either in the Performance or Supportability sections of the APB. The acquisition program baseline status of each program is reviewed once a quarter and at major reviews (Ryan, p. 36).

b. Acquisition Decision Memorandum (ADM)

When a program reaches a major milestone or experiences a significant change in its program parameters, the outcome is documented in an ADM. The ADM serves to document decisions made by the MDA, and typically includes additional directive statements that the PM must comply with. The Acquisition Decision Memorandum statements and directives are an opportunity for the MDA to encourage the achievement or improvement of reliability levels, while placing exit criteria, constraints, or follow-on actions related to reliability on the programs.

3. Requirements Generation Process

As this section will indicate, the Requirements Generation Process *can* serve as an initial primary tool for the Marine Corps to document quantifiable system reliability requirements in the Operational Requirements Document (ORD) in the form of Key Performance Parameters (KPP). Reliability requirements definition is the translation of warfighters' operational requirements into specific reliability requirements that can be defined, designed to, and measured. The requirements definitions are incorporated in written specifications that contain numerical statements of required reliability and precise description of the performance and environmental requirements that must be met to achieve the numerical reliability requirements. Close attention must be given to such reliability requirements because they are eventually used as contractual and acquisition devices to assure mission success and performance over time (Reliability, Maintainability, and Supportability Guidebook, SAE, p. 73).

a. Mission Needs Statement (MNS)

All acquisition programs are based on identified, documented, and validated mission needs, resulting from ongoing assessments of current and projected capability with respect to changing military threats and the National Security Strategy (NSS). Within the Marine Corps, part of MCCDC's overall mission is to translate

deficiencies and desired capabilities into operational requirements. Requirements determination and revision follow an established process, beginning with the Capability Review System within MCCDC where deficiencies are manifested by the Fleet Marine Force (FMF) through Fleet Operational Need Statements (FONS), the Marine Corps Lessons Learned System (MCLLS), Mission Area Analysis (MAA), and the Marine Corps Master Plan (MCMP). Additionally, the natural expiration of service life of equipment is factored into the process. A material solution to a deficiency begins with a broad statement of the requirement as outlined in a Mission Need Statement (MNS), developed by MCCDC, and sent to the Assistant Commandant of the Marine Corps ACMC for approval. The MNS is a non-system specific statement of operational capability need written in broad operational terms. It is non-specific by design and offers a materiel solution in one of three ways: improvements to an existing system, procurement of a non-developmental item, or begin a new research and development program. Subsequent approval and signature of the MNS by the ACMC constitutes a "validated requirement" and initiates Milestone A. Following the Mission Need Statement, MCCDC performs individual Analysis of Alternatives (AoA), and although not a requirements document, it forms the basis for an Operational Requirements Document (ORD), which is also drafted by MCCDC (USMC PM Acquisition Procedures Handbook, p. 1-6). It is through the AoA that an approach is formulated to set and refine life cycle cost objectives.

b. Operational Requirements Document

The ORD is a key document in the acquisition process, for it translates the MNS into more detailed and refined performance capabilities and characteristics of a proposed concept or system. To do so, the ORD defines the requirement, states the numbers of systems and where they should be fielded, and describes the specific operational capabilities required. MCCDC acts as the Combat Developer, and develops the Operational Requirements Document, which details the required system capabilities and characteristics to include the user's definition of system reliability parameters in operational terms. MCCDC is ultimately responsible for defining the requirements relative to the reliability of the system. It is at this stage that defining the "essential qualitative and quantitative readiness and logistics supportability requirements in

operational concepts and requirements documents is the most effective way for users to influence the design of their systems" (Department of Air Force, Instruction 10-602, 1994). Typically, this is defined in terms of operational availability and mission duration needs. As directed in DoD 5000.2-R, these operational performance parameters are to be stated as Objectives and Thresholds. Section 2.6 of DoD 5000.2-R states

> supportability factors are integral elements of program performance specifications. However, support requirements are not to be stated as distinct logistics elements, but instead as performance requirements that relate to a system's operational effectiveness, operational suitability, and life-cycle cost (DoD 5000.2-R).

Reliability, along with cost, schedule, and performance, should act as equal partners in the requirements generation process. An effective way to ensure that a system maximizes its operational availability is to include robust reliability goals in the ORD.

At each milestone, beginning with program initiation, thresholds and objectives initially expressed as measures of effectiveness (MOEs) and minimum acceptable requirements for the proposed concept or system are documented by the user or the user's representative in the ORD to quantify system level performance. Thresholds and objectives in the ORD consider the results of the analysis of alternatives and the impact of affordability constraints (DSMC, "Acquisition Logistics Guide", p. 5-2). The Combat Developer's definition of the intended reliability requirement is an essential element in establishing the basis for any successful reliability program. Whether the requirements result from the needs of the user or from internal goals identified by a design or project organization, well-defined requirements are needed. Conversely, poorly defined requirements lead to conflicts in direction and inefficiencies in the application of engineering and management resources. If the requirements are defined properly, close adherence to the ORD is necessary for a successful logistics program (Reliability, Maintainability, and Supportability Guidebook, SAE, p. 42).

Reliability requirements determination is not accomplished in a vacuum. In fact, developing quantitative operational reliability requirements, like all other ORD requirements, is a collaborative process between the combat developer (MCCDC) and the

materiel developer (MARCORSYSCOM) using Integrated Product Teams (IPTs). This process provides a balanced solution between the best estimate of what is required to meet the warfighter's effectiveness, suitability, and survivability needs, and that which is actually affordable and technically achievable within program funding, risk, and time constraints (Ryan, p. 13).

c. Key Performance Parameters

While the ORD serves to establish minimum acceptable operational values for broad performance parameters, the Marine Corps has the *opportunity* to include quantifiable and understandable reliability requirements as Key Performance Parameters (KPPs) in the ORD. A KPP is a capability or characteristic that is so significant that failure to meet the threshold can be cause for the concept or system selection to be reevaluated or the program to be reassessed or terminated. By placing reliability requirements as KPPs in the ORD, contractors would be required to test to reliability. Such KPPs would likely ensure adequate logistics weight in source selection. Unfortunately, reliability (as well as availability and maintainability) requirements are usually not KPPs, and when there are cost or schedule overruns, reliability is sacrificed. In reality, reliability KPPs should be expressed with both threshold (minimally accepted values) and objectives (what the user desires and what the PM is attempting to obtain). Then, given a system's reliability goal that is clearly defined by the Combat Developer as a KPP in the ORD, the designer understands what reliability the system should be "designed to."

Part of the intent of new 5000 series and the new acquisition model is to reduce Total Ownership Costs (TOC) by minimizing the number of mission-oriented Key Performance Parameters. Upper levels of DoD believe that this maximizes the PM's and contractor's flexibility to make cost/performance tradeoffs without the unnecessary higher-level permission, proving to be essential to achieving cost objectives. Therefore, the number of threshold items in requirements documents and acquisition program baselines are strictly limited. The threshold values represent true minimums, and the requirements should be stated in terms of capabilities rather than technical solutions and specifications. While reliability related KPPs typically are not in the ORD, many professionals will argue that they should be a mandatory part of the ORD.

4. Contracting

As the previous section indicates, to attain a desired combat capability, or operational thresholds and goals, requirements must be communicated in the ORD in clear operational terms, a responsibility of the Combat Developer. The reliability objectives must then be translated into quantifiable and verifiable contractual terms traceable back to the operational requirements. The Materiel Developer must adequately translate the system operational terms into viable contractual terms understood by all parties involved to include the user, the program office, and the contractor so that compliance can be adequately monitored and enforced. Previously in the traditional acquisition process, the Materiel Developer could insert reliability requirements in the system specification and development specifications and then incorporate tasks in the statement of work (SOW), allowing the contractor to conduct a disciplined reliability program to achieve the requirements (SD-2 "Buying Commercial and . . .", Ch. 6). However, recent policy changes resulting from the military specifications and standards reform in 1994 has led to the incorporation of a performance-based approach to reliability in Request for Proposals, eliminating the use of "how to" reliability standardization documents.

a. Performance Specifications

The MNS, AoA, and ORD are provided to the Materiel Developer (MARCORSYSCOM) for performance specification development, or the translation of user requirements into performance specifications that should be understandable to potential contractors. Performance specifications eventually become major pieces to the Request for Proposal (RFP) and the contract, and thus, they are to clearly state what the system must do, how well it must perform, under what circumstances and conditions, and identify other constraints. However, performance specifications do not dictate to contractors how to achieve the required performance.

It is important to note that developmental testing is conducted to contractual and performance specifications, while operational testing is conducted to ORD operational thresholds. "The operational user, the program offices, and the contractor often get very confused over the process of translating ORD (operational threshold) numbers to contract (performance) specifications and vice versa" (DSMC,

"Acquisition Logistics Guide", p. 10-6). The user or warfighter often has various measures highlighted in the ORD that must be translated by the program office into performance specifications. Table 3.1 provides a sample of user measurements compared to the common contractual reliability specification of MTBF.

USER OBJECTIVE AREA	**RELIABILITY (MTBF)**
----- Operational Effectiveness -----	
Increase Readiness	Mean Time Between Downing Events (MTBDE)
Increase Mission Success	Mean Time Between Critical Failures (MTBCF)
----- Ownership Costs -----	
Decrease Maintenance Personnel Costs	Mean Time Between Maintenance Actions (MTBM)
Decrease Logistic Support Costs	Mean Time Between Removals (MTBR)

Table 3.1. Measures of Systems Readiness. (From: DSMC, "Acquisition Logistics Guide", p. 10-6)

There must be a clear connection between the defined operational reliability requirements in the ORD, created by the Combat Developer and the performance specifications completed by the Materiel Developer in the terms of the contract. Conversion of commonly used operational terms such as MTBM and MTBCF must be made to enable translation to parameters that can be specified in contracts as well as verified in testing. In doing so, one of the major difficulties is attempting to merge contractual reliability and operational reliability.

CONTRACTUAL RELIABILITY	OPERATIONAL RELIABILITY
• Used to define, measure and evaluate contractor's program • Derived from operational needs • Selected such that achieving them allows projected satisfaction of operational reliability • Expressed in inherent values • Accounts only for failure events subject to contractor control • Includes only the design and manufacturing characteristics **TYPICAL TERMS:** • MTBF (Mean Time Between Failure) • Mission MTBF (sometimes called MTBCF)	• Used to describe reliability performance when operated in the planned environment • Not used for contract reliability requirements (requires translation) • Used to describe the required level of reliability performance • Includes the combined effects of item design, quality, installation/repair environment, maintenance policy, repair, etc. **TYPICAL TERMS:** • MTBM (Mean Time Between Maintenance) • MTBD (Mean Time Between Demand) • MTBR (Mean Time Between Removal) • MTBCF (Mean Time Between Critical Failure)

Table 3.2. Contractual vs. Operational Reliability. (From: Reliability Engineers Toolkit: Rome Laboratory)

b. Source Selection Factors

The Marine Corps also has the opportunity to use reliability as a factor in source selection, arguably the most important contractor motivational factor. In source selection for a modified or new system, reliability must be singled out as a specific evaluation sub factor. Reliability should be a performance requirement used in the solicitation process. In other words, reliability plans and goals should always be a source selection evaluation sub factor.

In the solicitation process, Request For Proposals (RFPs) include a strict minimum number of critical performance criteria that force contractors to meet the desired program objectives. The desired reliability and cost objectives can be used as a management or leveraging tool that forces contractors to meet such objectives. Because potential suppliers are competing for a contract, there is a natural tendency for contractors to emphasize their strengths while concealing their weaknesses. While it is often useful to utilize contractor testing results, it is important to ascertain their capabilities through probing, questioning, and eventually, independent military testing as will be discussed in an upcoming section.

c. Contracts, Clauses, Warranties, and Incentives

After reliability requirements have been established, "the apportioned values (MTBF, MTTR, and/or relevant criteria) should be included in appropriate sections of procurement specifications, critical item specifications, and contractor end-item specifications" (DSMC, "Designing Quality Into Defense Systems", p. 17). The contractor and designer must clearly understand every critical requirement the system must meet so that if needed, trade-offs can be executed based on government priorities.

While predicted reliability typically comes from contractor claims, the DoD needs some confidence level that it is a good system of merit for predicted reliability. The Materiel Developer must attempt to contract to a given or specified reliability confidence level or to a commitment to a specified target operational availability in an effort to hold contractors accountable to their original reliability estimates. When dealing with contractors' predicted reliability, the null hypothesis that the estimate is incorrect should be assumed until proven otherwise.

Additionally, the contracts resulting form the source selection should have incentive clauses related to the level of reliability achieved and verified. Warranties can be utilized to hold contractors responsible for sustaining in the operational environment, the performance levels which have been contractually agreed to. Then, if the contractor does not meet the contractual reliability goals, reliability shortfalls *should be* considered a latent defect. Additionally, incentives such as cash rewards can be used to motivate contractors to exceed minimum program requirements and predetermined thresholds for reliability. However, the use of contract warranties and incentives sometimes imposes unrealistic data collection demands on the operational user and field maintenance organization, making it difficult to enforce the warranty provisions. The operational scenario must be evaluated to determine if warranty conditions are practical. Unfortunately, in the past,

> PMs often disregard(ed) logistics contract considerations, such as identifying logistics deliverables and creating the logistics input to the Statement of Work (SOW), as long-term issues that are less important than the immediate problems. As a result, logistics concerns are (were) often deferred for later resolution (DSMC, "Acquisition Logistics Guide", p. 17-8).

One of the more recent trends has been experimentation with Contractor Logistics Support (CLS), which has shown indicators of lower costs and/or increased readiness. Under CLS, the performance of maintenance and/or materiel management functions for DoD systems is conducted by commercial activities. A discussion of the benefits and challenges of CLS are beyond the scope of this thesis.

Another recent initiative has been the use of Performance Based Logistics (PBL) and Performance Based Payments (PBP). This strategy is a method of providing financing to contractors, performing under fixed-priced contracts, where performance based payments are given upon the achievement of specific events or accomplishments that are defined and valued in advance by the parties to the contract, rather than being tied to and based upon incurred costs of performance (DoD Users Guide to Performance Based Payments, Chap 1). It is an integrated acquisition and logistics process for buying weapon system capability and instead of buying set levels of spares, repairs, tools, and data, there is a focus on buying a predetermined level of availability to meet the warfighters' objectives. In PBL, the contract requirement is specified in service terms. For example, the number of hours at a given cost per hour and customer response-type metrics such as availability may be used to describe the service. When properly incetivized, the PBL provider strives for continuous improvement in reliability to eliminate his maintenance efforts altogether.

The bottom line remains that,

> the well-meaning but ineffectual philosophy often applied to reliability – 'we will do the best we can' should be replaced by a contractual obligation in the form of quantitative system reliability requirements that forces contractors to consider reliability equally with other system parameters such as performance, weight, cost, etc (Kececioglu, "Reliability Engineering Handbook," Chap. 15).

To do so, contracts and contract warranty clauses must be specific while the user, the program office, and the contractor must understand and agree to the reliability terms in both the ORD and contract specification. Ultimately, reliability and logistics program success are a direct reflection of contract success.

5. Conceptualization, Design, and Development: Systems Engineering Process

System effectiveness and cost are the drivers in design decision, and given the trend towards the development of increasingly complex weapon systems, it is obvious that reliability cannot be ignored and left as a matter of chance when considering design. Instead, reliability must be consciously and proactively built into systems through effective design and manufacturing practices. The method for doing so is the systems engineering process (SEP), which is used to translate operational needs and requirements into a system solution that includes the design, manufacturing, test and evaluation, support processes, and products. This includes transforming operational needs and requirements into an integrated system design solution through concurrent considerations of all like-cycle needs.

A major goal and function of the systems engineering process is the achievement of a proper balance cost, schedule, risk, and performance (to include readiness and supportability). To do so, supportability analyses are conducted as an integral part of the systems engineering process, beginning at program initiation and continuing throughout system development. Supportability analyses form the basis for related design requirements included in the system specification and for subsequent decisions concerning how to support the system in the most cost-effective manner over its entire life cycle (DSMC, "Acquisition Logistics Guide", pp. 3-10 – 3-12).

The system engineering process is an iterative interdisciplinary problem solving methodology that allows the Government and the contractor to create an integrated and life cycle balanced set of system product and process solutions based on Government performance specifications and system requirements. The process serves to determine critical interfaces for system integration by progressively decomposing system requirements into performance specifications and defining all subsystems, assemblies, and parts. As a result, the SEP assists in verifying that the system design meets user requirements. While the system engineering process is typically applied at the prime contractor level, relevant requirements are passed down to the subcontractor/supplier/vendor levels. Figure 3.3 illustrates the iterative nature of this process.

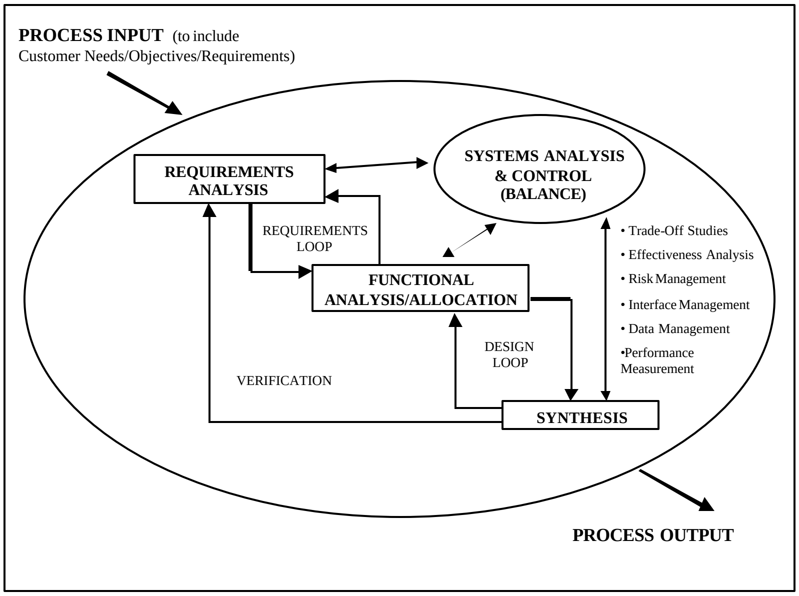

Figure 3.3. Systems Engineering Process. (From: DSMC Program Managers Tool Kit, p. 65)

Application of the system engineering process to reliability design is accomplished through a structured process of functional analysis, design synthesis, alternative exploration, trade-off evaluation, and decision making which is iterated throughout the design process to achieve the desired levels of performance. Maximum benefit accrues through the integration of reliability into the system engineering process during early development activities since most of the system life cycle costs are determined in the early phases of development. The SEP is based on the Integrated Product Process Development (IPPD) framework, which is a management technique that simultaneously integrates all essential acquisition activities through the use of multi-disciplinary teams to optimize the design, manufacturing, and supportability processes. The multi-disciplinary aspect of SEP serves as an effective way to get the various disciplines working together. Thus, systems engineering programs are required by DoD 5000.2-R for all Acquisition Category (ACAT) programs.

The balanced integration of logistics considerations into the systems engineering process is imperative from the onset. System reliability, maintainability, and

supportability must be key elements of the tradeoff and design criteria in each stage of the process as design considerations will inevitably be in conflict with reliability, maintainability, and supportability goals. When such conflicts do occur, the latter goals must be considered equally with acquisition cost, schedule, and performance. The logistician must be a principal player in the development process as indicated in the below excerpt from MIL HDBK-502.

> Unfortunately, acquisition logistics (supportability) objectives often conflict with other design objectives like speed, range, size, etc. How is this inevitable conflict resolved? Early in the process, the issue of tradeoffs must be raised during the analysis of proposed concepts. Careful use of tradeoff studies will guide the engineers and the logisticians in finding the optimal design -- one which balances design objectives with supportability requirements. Tradeoffs are an essential part of the design process.
>
> The result of this early collaboration between engineering and logistics personnel is a specification that prescribes performance requirements to be achieved.
>
> The challenge is to ensure that supportability is integrated into the program from the beginning phases. The early design phases of a project, when things change rapidly, may seem of little interest to logisticians, and their attendance at engineering design reviews may seem a waste of time. Actually this period has far reaching logistics impact. During this phase the logisticians can use the leverage of early program involvement to identify approaches that will significantly lower life cycle costs. They may be able to catch an exorbitantly expensive material or time-consuming maintenance process before it has become integrated into the system (MIL HDBK-502, 6.2.1).

6. Test, Production, and Verification

> One must learn by doing a thing; for though you think you know it, you have not certainty until you try. - Sophocles

Once a system has been selected, it is imperative to demonstrate, through testing, that system capabilities meet contract specifications and satisfy mission needs. Specifically, as the proceeding sections will indicate, reliability demonstrations and consequential logistics and supportability factors must be included as part of the testing, production, and verification of new weapon systems. Unfortunately, demonstration of required reliability performance levels prior to system fielding is often a challenge.

Because the logistical support system will be built upon the accepted reliability estimates, the verification of reliability figures is crucial. It is during testing that DoD organizations must validate the contactors' reliability estimates in an effort to avoid future unexpected life cycle cost, supportability, and readiness problems as weapon systems mature. Based on system design and its reliability and maintainability predictions, the PM office will determine the number of spares of each particular type that will be purchased, what support equipment will be used, whether new equipment will be procured, the types of skills needed and the varying skill levels required as well as other manpower considerations, funding requirements, and POM considerations. If the USMC is basing its Integrated Logistical Support Packages (ILSP) upon initial contrac tor reliability estimates prior to fielding, it is imperative to have accurate reliability estimates. Unfortunately, contractor reliability estimates (of systems and their components) are sometimes far different from the actual achieved reliability of fie lded systems, causing possible catastrophic effects, readiness degradation, or enormous and unexpected Life Cycle Costs which eventually create additional need for O&S dollars in later years.

Testing (to include reliability testing) serves several general purposes: 1.) to gauge the progress being made when a concept is being translated into an actual product; 2.) to mature the system by revealing design and process deficiencies so that corrective action may occur when it is least costly to fix; and 3.) to determine compliance with the requirement and determine operation suitability through formal qualification or demonstration testing prior to fielding. There are many types and levels of technical and operational tests that are available and used by both contractors and the government. While discussion of such tests are beyond the scope of this thesis, some of the common tests include but are not limited to: simulations, environmental stress testing, accelerated life testing, reliability development/growth testing (RD/GT), reliability qualification (RQT)/demonstration testing (RDT), developmental test and evaluation (DT&E), operational test and evaluation (OT&E), early user test (EUT)/Limited User Test (LUT), initial operational test (IOT), life fire test and evaluation (LFT&E), follow-on test (FOT), and many more. For general background purposes, the next sections will briefly examine DT&E and OT&E, the two most general categories that of DoD testing. Table 3.3 serves

to further distinguish between developmental and operational testing while complementing the proceeding sections.

DEVELOPMENTAL TEST & EVALUATION	OPERATIONAL TEST & EVALUATION
• Technical performance measurement • Developing agency responsibility (PM) • Technical personnel • Limited test articles / each test • Controlled environment • All types of test articles / prototypes • Government / contractor involvement	• Designed to obtain operational effectiveness / suitability data • Operational Test Agency Responsibility (MCOTEA for USMC) • "Typical" user personnel • Realistic combat environment and threats • "Production Representative" test articles / LRIP items • Contractor involvement restricted

Table 3.3. DT&E and OT&E Comparisons. (From: DSMC PM Toolkit, p. 51)

a. Developmental Test and Evaluation

The overall goal of developmental testing is to determine whether the weapon system meets the technical contract and performance specifications. DT&E is a method for the PM to *make the system work*, to verify contractor claims and predictions, and to influence the system design. Such testing assists in the development and maturation of products, product elements, and support processes and is utilized to verify the status of technical progress, verify that design risks are minimized, and certify readiness for initial operation testing. While both contractors and Government personnel are involved in DT&E, the tests are generally accomplished by engineers, technicians, or operator-maintainer test personnel in a controlled environment to facilitate failure analysis.

The feedback provided by developmental testing allows those personnel involved in the systems engineering process to analyze the test results and implement required adjustments before testing again. As expected, reliability engineers and

logisticians play a critical role during DT&E through the IPT process. However, the Program Manager ultimately controls the DT environment and is provided with the data throughout the testing cycles, enabling the PM to make informed managerial decisions that affect the reliability of the final product. Developmental testing identifies capabilities and limitations of alternatives and comparisons of candidates. The PM typically is forced to make cost-performance trade-off decisions before eventually certifying that the system is ready for operational test and evaluation (OT&E).

b. Operational Test and Evaluation

Operational testing is the *field test* for any system or key component of the weapon system, conducted under realistic conditions, to determine the operational effectiveness and suitability of the system for use in realistic combat conditions by typical military users. Operational testing should determine whether minimum acceptable operational performance requirements (ORD thresholds) have been satisfied. Unlike developmental testing, operational testing is conducted by independent military test organizations not beholden to the program office, which represent the customers or combat units that will ultimately use the systems. As a result, operational testers typically have more independence than developmental testers as they provide their results to Congress as well as to senior officials in the services and the Office of the Secretary of Defense (GAO, "A More Constructive Test . . .", p. 11)

c. Testing Summary

Despite what category or level of testing is being conducted, credible and properly designed tests must be addressed, conducted, and properly evaluated early in the development process for results to be useful. However, weapon system programs have traditionally suffered from persistent problems associated with late or incomplete testing. While discovery of problems in any complex product (through testing) is a normal and desired part of the developmental process, surprises in testing or repeated occurrences often polarize organizations into proponents and critics of programs. It is difficult for weapon system programs to compete for approval unless the system offers significantly better performance over other systems while remaining within available funding and scheduling constraints. As a result, there are greater incentives for PMs to "accept immature technologies and make optimistic assessments about what can be accomplished

with limited resources." Test results tend to become scorecards that demonstrate whether the program is ready to proceed or to receive the next increment of funding. In the DoD, unlike in the commercial sector, testing and evaluation is more for the benefit of the testers and decisionmakers above the program manager. Thus, managers often have incentives to postpone difficult tests and to limit open communication about the test results (GAO, "A More Constructive Test . . .", p. 8-9).

7. Maintaining Reliability of Fielded Systems

Managing reliability does not end with OT&E and fielding of the system, and instead, reliability must be continually monitored and assessed for potential improvements and efficiencies in support of meeting Marine Corps life cycle cost and readiness objectives. In fact, once a system is fielded, reliability assessment should become a permanent part of sustainment activities conducted by Program Management Offices as well as other Life Cycle Management organizations. To be successful, reliability growth must continue during the customer-use phase by coordinating feedback from the warfighters to the suppliers and by supporting necessary corrective actions. Part of Phase III (Production, Fielding/Deployment, & Operational Support) responsibilities include ensuring fielded systems continue to meet mission requirements *throughout their planned life cycles*. Specifically, critical systems and components should be identified where low reliability rates are degrading readiness and causing unnecessary support costs.

The basic policy of DOD is to hold contractors responsible for quality of the products through quality assurance programs. Quality assurance is defined in DODD 4155.1 as "a planned and systematic pattern of actions necessary to provide adequate confidence that material, data, supplies, and services conform to established technical requirements and achieve satisfactory performance" (DSMC, "Designing Quality Into Defense Systems", p. 8). This obviously requires a plan and action, which must be based on the quality requirements as outlined in the ORD. To do so, it is recommended that a program use the reliability requirements stated in operational requirements, or those resulting from trade-off analysis, as a baseline for reliability assessment to be compared with actual achieved field reliability. However, the difficulty remains in collecting, interpreting, comparing operational (achieved) reliability with contractual reliability

measurements as illustrated in the previous Table 3.2. Aside from the essential collection of achieved field data, original contractor estimates and requirements must be retained for comparison. It may not be surprising to find that such documentation is not typically retained and is difficult to locate.

An example of the difference between inherent (or potential) reliability and achieved value is shown graphically in Figure 3.4. The operation and maintenance of equipment in the field can induce these effects by stressing systems beyond predicted levels. Additionally, the true achieved reliability can be obscured by scheduled and unscheduled maintenance actions and the corresponding incorrect administrative actions. Operational contributors to such overstresses include neglect, unfamiliarity, carelessness, and mission constraints. Maintenance actions can also induce defects in otherwise satisfactory assemblies; foreign objects introduced, fasteners improperly engaged, contaminants introduced, improper part replacement, improper lubricants, etc. While a major effort is made in operations to reduce the effects of reliability degradation caused by maintenance, the designer should consider the risks of field maintenance and minimize the characteristics of the design that are susceptible to operationally induced reliability deterioration. Equally important, reliability predictions should be made on realistic operational projections for degradation. (DSMC, “Designing Quality Into Defense Systems”, p. 28)

However, it can be argued that reliability requirements can and should be established for each phase or product life cycle of a system such as storage, transportation, installation, standby, and operation. Therefore, a realistic reliability requirement must account for all application environments and the time proportions expected in each, and an apportionment of the requirement across the life cycle phases accounts for deterioration in each phase (Reliability, Maintainability, and Supportability Guidebook, SAE, p. 75). Ultimately, perhaps contractors should attempt to account for all elements contributing to the combined failure rate (Table 2.1) and provide the government with a confidence interval for a predetermined readiness performance in the form of operational availability. Such ideas are open to dispute and will be discussed in the upcoming analysis chapter of this thesis.

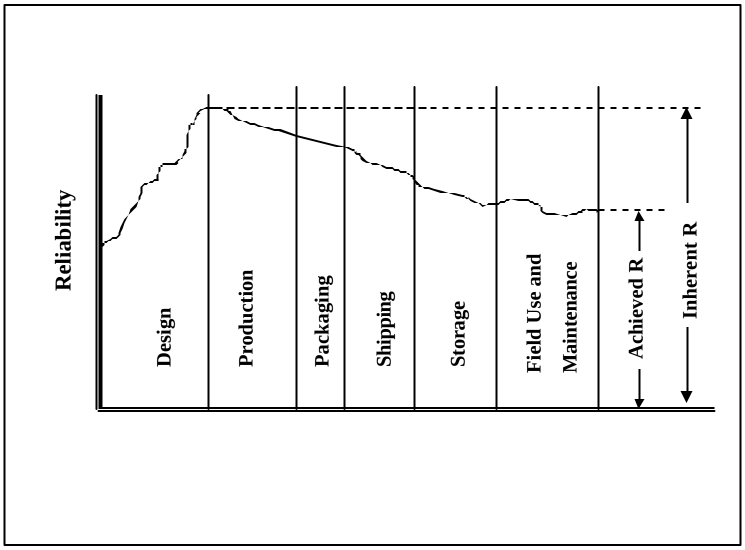

Figure 3.4. Sustaining Reliability in Production and Service. (From: DSMC, "Designing Quality into Defense Systems", p. 28)

D. CHAPTER SUMMARY

Beginning with the initial requirements generation, through each iteration of the systems engineering process, and ultimately during post-production, reliability must be planned for, monitored, accessed, and improved during the maturation of a weapon system. The greatest impact on life cycle cost and future operational availability are realized during the early phases of system design and development, and thus, logistics and the design for supportability must be inherent within early system design development if the results are to be cost-effective. The Department of Defense (DoD) must continue to strive for the integration of acquisition and logistics in an effort to ensure a superior product support process by focusing on total ownership cost, supportability as a key design and performance factor, and logistics emphasis in the systems engineering process (DSMC Acquisition Chart, 2001). Reliability must be the focus of such core planning. Fortunately, as discussed in this chapter, many opportunities exist throughout all phases of the acquisition process to effectively address reliability.

The next chapter examines reliability management techniques and methodologies utilized by program management offices as well as common issues and inhibitors

associated with reliability management. The data was collected via an electronic survey and the results are presented in aggregate form, organized by general themes.

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IV. MANAGING RELIABILITY IN ACQUISITION PROGRAMS

A. INTRODUCTION

This chapter explains the methodology utilized for data collection and presents the data gathered to address the primary and subsidiary research questions. The data collected relates to a variety of technical, programmatic, managerial, and procedural issues and concerns; common practices; and acquisition experiences that relate to reliability. The data presented reflects the actions, experiences, and perceptions of the acquisition workforce that deals with reliability management issues within the Marine Corps. The primary source of data collection was a web-based reliability performance survey that was distributed to targeted program management offices via the Acquisition Logistics Office at Marine Corps Systems Command. The survey was a modification of a similar survey, previously distributed to a Program Executive Office within the Army acquisition community, as well as from the literature review and the background research on reliability, described in Chapters II and III. A copy of the survey can be found in Appendix B. It should be noted that the survey data from the responding program offices is presented in aggregate form, organized by general themes, and summarized in tables created by the author.

B. METHODOLOGY

In an effort to determine the current environment for reliability management within the Marine Corps acquisition community, the researcher administered an electronic survey to various personnel within the Program Offices of specific critical/pacing end items. The survey directions requested attention be given by upper level management personnel such as the PM or deputy PM. Respondents included Program Managers, Program/Project Team Leaders, reliability engineers, and heads of the logistics engineering divisions. The questions posed were intended to emphasize the perspective of program management leadership on the varied tasks involved with reliability management. In addition to the qualitative-natured questions concerning management and procedural issues, numerous quantitative questions were included to determine and compare required reliability, estimated or predicted reliability, and achieved reliability. As a supplemental source to gain insight into reliability management

issues, interviews were also conducted with current acquisition professionals familiar with program and reliability management, to include personnel from various program offices, the test community, reliability management disciplines, various studies and analyses branches, and personnel from academic disciplines.

1. Program Demographics

The systems originally *intended* for research were limited to mature critical/pacing end items included in the Quarterly Readiness Reports to Congress (M1A1 tank, AAV family of vehicles, LAV family of vehicles, 5-ton truck family of vehicles, HMMWV family of vehicles, MK-48 LVS Power Unit, and M198 Howitzer). All the programs are Acquisition Category (ACAT) level I and are part of the Marine Corps ground equipment inventory. However, it should be noted that some of the systems were procured with the Army acting as the executive agent.

Legacy systems, as opposed to systems in development or recently fielded systems, were targeted due to the *expected* availability of achieved field reliability data, which was to be compared with required and estimated reliability. Due to the operational age of the systems, replacement systems are currently in development for several of the systems.

As a result of non-participation by a significant portion of the targeted programs, additional willing participants, largely from the AAAV program office, offered input to the qualitative portion of the survey. However, due to the early stage of the AAAV development, the quantitative data questions on estimated and achieved field reliability were not applicable to the program.

2. General Survey Question Themes

The research was intended to evaluate how weapon system reliability performance is managed throughout the acquisition process by identifying common inhibitors and enablers of effective reliability management, why they occur, lessons learned, and potential methods for mitigating the inherent risks. To do so, the survey consisted of 37 primary questions, some with subparts, which focused on five major themes, developed for the purpose of this thesis, and listed below:

- management approach to reliability
- determining and documenting reliability requirements

- contracting and incentivizing for reliability
- reliability testing
- comparing and assessing required, estimated, and achieved field reliability

Collectively, these themes correspond to issues addressed in the thesis research questions.

3. Data Presentation

In an effort to obtain disclosure of all issues associated with reliability management, respondents were permitted to provide information under the premise of non-attribution. Likewise, survey instructions specifically stated that all program responses would be presented in aggregate form. Responses were received from only three of the seven programs originally solicited for participation. As a result, the researcher sought additional programs for participation to gain further perspectives on reliability management issues. The additional programs were incorporated through their survey responses, interviews, and email correspondence.

The subsequent sections provide the data for this research and serve as the basis for analysis in Chapter V. The survey responses and corresponding data are organized into the previously mentioned five major themes.

While all the themes have subparts, each theme is generally presented in the same fashion. First, the purpose of the survey questions within that main theme is addressed. Next, narrative summaries of responses, data tables, illustrative examples of reliability management experiences, responses in the form of quotes, or a combination of such, are presented. Lastly, the author summarizes the responses and data to exemplify challenges that program managers face when dealing with reliability issues of their systems.

C. MANAGEMENT APPROACH TO RELIABILITY

Purpose of Theme: The first series of survey questions focus on how reliability and its associated risks are managed. The questions asked the program offices: 1) what they perceived to be the key factors that contribute to reliability problems in a program; 2) how reliability performance is managed within a PMO in terms of roles and responsibilities, documentation, and activities utilized to recognize and evaluate potential system failures; and 3) their opinion and understanding of the amount and adequacy of DoD and USMC policy and guidance on reliability.

1. Key Factors Contributing to Reliability Performance Problems

Given a list of fifteen common prevailing issues, the survey participants were asked to rank order what they perceived to be the top five factors that contributed to reliability problems in program management. Respondents were also given the opportunity to nominate "other issues" and rank them relative to the fifteen issues provided in the survey. Table 4.1 provides a compilation of the top responses, presented in an overall composite order of merit ranking, from the most significant factor to the least significant.

Survey Responses:

TOP RATED FACTORS CONTRIBUTING TO RELIABILITY MANAGEMENT PROBLEMS
1. Traditional test & evaluation RAM metrics are not supported by maintenance data sources (unable to make a valid comparison b/n RAM requirements and estimates with achieved field data)
2. Too much pressure to field systems rapidly (schedule goals outweigh reliability)
3. Need more qualified reliability personnel in PMOs
4. Unrealistic reliability requirements with inadequate rationale
5. Poor reliability planning and growth planning (test too late)
6. Missing or poorly written ORD reliability requirements
7. Insufficient reliability testing to verify requirements
8. Contractor not designing for reliability sufficiently above the requirement
9. Too much pressure to field system cheaper (cost goals outweigh reliability)
10. Not consistently improving reliability after fielding
11. Inadequate or vague policies and guidance (need updating)

Table 4.1. Top Reliability Management Problems as Perceived by Survey Respondents within the Acquisition Community.

Given the opportunity to nominate their own factors affecting reliability management, several respondents did so, providing the following comments:

- PMs are not provided the resources or authority to impact reliability
- Engineers pay more attention to meeting performance requirements than to reliability requirements when they should be considered more equally
- Traditionally, PMs have been evaluated on cost, schedule, and performance. Thus, reliability often got pushed aside

- The PMs, the Primes, and all the members of the IPTs should be evaluated on readiness performance that have force of law
- Currently, PMs are graded on cost (testing costs and costs to field), schedule, and performance in accordance with the Defense Acquisition Executive Summary (DAES) vs. SUPPORTABILITY, in the form of LCC or some target A_o
- Dollars drive the train (acquisition process) instead of requirements

Summary: The top three inhibitors to effective reliability management, as ranked by the survey respondents, were clearly identified as problematic as all of the respondents chose all three of these choices as one of their top five ranked issues. Interestingly though, twelve of the fifteen (survey-provided) choices received two or more votes, and five of the fifteen choices received at least one vote as the top inhibitor to effective reliability management.

2. Managing Reliability in Acquisition Programs

The next series of questions deal with program management approaches to reliability, to include the perceived roles and responsibilities of dealing with reliability, formal documentation of a reliability program plan, and activities utilized to recognize and evaluate potential system failures.

a. Reliability Roles and Responsibilities

Survey participants were asked, "who within the organization was primarily responsible for program reliability activities." The author desired to determine how PMs delegated responsibility for reliability activities and whether there was a consistent managerial approach in doing so. If the respondents indicated that reliability activities were conducted within the context of an Integrated Product Team (IPT), responders were asked if the IPT was formally chartered.

Survey Responses: Responses varied throughout the programs without any overwhelmingly unified response. The most common responses indicated that either Logistics/Supportability Team Leaders or Project Team Leaders had been delegated primary responsibility for reliability issues, each receiving two responses. Only the AAAV program indicated the use of reliability IPTs. Additionally, two programs recognized that the PM had ultimate responsibility while delegating reliability issues to Team Leaders and others. Lastly, one program respondent could not identify an

individual or team that had overarching responsibilities associated with reliability activities, choosing the "no one specifically" survey option, possibly suggesting a shared responsibility amongst multiple sources.

A former PM commented that PMs manage by exception and without a specific problem or issue, reliability and the other engineering disciplines are managed through empowerment of technical experts (Masiello, p. 39).

Summary: Responses varied as to the individual or group primarily responsible for program reliability activities, and responses included the PM, Reliability IPTs, Logistics Team Leaders, Project Team Leaders, and in one case, no one specifically. No survey responses indicated that primary responsibility for reliability fell upon the prime contractor, test team leader or testing activities, system engineering team leader, or the Logistics Management Specialists (LMS). Overall, PMs seemed to rely upon reliability competency outside the program through matrix support.

b. Documenting a Program's Reliability Approach

Survey participants were asked, "how the system reliability program and the corresponding management approach were formally documented within the program(s)." Choices included: reliability program plan, contract statement of work (SOW), test and evaluation master plan (TEMP), single acquisition management plan (SAMP), no formal reliability management plan, or other.

Survey Responses: Of the responses received, half of the programs indicated that there was no formal reliability program plan. One respondent noted, "there is no requirement for PMs to have a formal program or an overarching document describing the activities." Of the programs which had a reliability plan, most relied on the contract SOW or TEMP to address: 1) how they intended to ensure reliability was treated as a high priority objective, 2) methodologies and plans for measuring and achieving reliability, and 3) the resources needed to execute the plan.

c. Activities/Tools Used to Evaluate Potential Failures

There are numerous test and design tools available to program offices and contractors that help to ensure that reliability is "designed-in," early in the program.

"Designing-in" reliability upfront reduces risk and is less costly than finding design discrepancies during later stages of testing, evaluation, and operational use.

By inquiring as to which "activities that the program(s) implemented to recognize and evaluate potential failures and causes," the author's intent was to determine the risk mitigation techniques which programs and contractors employed to address reliability achievement. The survey asked participants to identify all the testing, engineering, and other technical methods used in their respective programs. A list of fifteen common testing, engineering, and other technical methods and techniques used to determine and evaluate potential failures and their causes was provided for survey respondents to choose from. Additionally, participants were provided the opportunity to list any other methods utilized by their programs.

Survey Responses: As expected, developmental and operational testing played a major role in the development of all programs. However, the extent to which programs failed to utilize other reliability risk mitigation techniques to determine reliability achievement was rather astounding. There was one outlier, which was the only system examined that is currently in development. While the AAAV program respondents indicated the use of all fifteen techniques listed, the other program respondents either had very scarce use of the tools or were not aware whether the original program staffs and contractors had used the techniques.

Each program indicated that it utilized only one of the following techniques: Environmental Stress Screening (ESS), reliability modeling, FMECA, Reliability Development/Growth Test (RD/GT), or FRACAS. Additionally, no program indicated the use of reliability allocation, fault tree analysis, probabilistic failure assessment, reliability qualification test, PFMEA, Weibull analysis, physics of failure (POF), or a parts control program. One reliability engineer indicated, "we list all of the tools that we think will be useful, knowing that PMs will cut many of them, citing fiscal constraints" (Masiello, p. 47).

Summary: Many program representatives were either not aware of the specific techniques utilized to ensure reliability was "built-in," or the original staffs did not actually use the available tools. However, there was a common consensus to test

early and often, and use knowledge of reliability growth to implement corrective action. All PMOs reported using some form of failure analysis as an integral part of the design process, and there was a consensus that the use of such tools that incorporate reliability prediction and achievement into system design was beneficial.

The reader should be reminded that in most cases, the survey respondents were not the original PMO staff, and the respondents may be aware of which techniques were utilized only by reviewing any existing documentation that was retained before their arrival. It is assumed that much documentation from the original staff or the contractor was no longer available. The assumption that the legacy systems did not take advantage of the reliability analysis tools may be invalid. In reality, many of the programs may have utilized the tools more than indicated in the survey, and the respondents were not aware of the previous staffs' or contractors' actions.

3. Existing Policy, Regulations, and Guidance on Reliability

The author wanted to determine the level of existence as well as the level of awareness of reliability policy, regulations, and procedures. Likewise, the author desired the opinions of the acquisition community as to whether the existing regulations and guidance were sufficient to help PMOs manage reliability performance in their programs. The questions posed to survey participants were, "Are you aware of any specific DoD or Marine Corps policy/regulations regarding weapon system reliability management? And, do you feel that existing policy and regulations on reliability provide adequate guidance?"

Survey Responses: Six of the seven respondents that chose to answer this question stated they were unaware or unsure of any policy or regulation regarding reliability management. The PM that answered in the positive did not cite a specific manual, document, handbook, or policy, and simply stated that it was the "program engineer's responsibility (to be aware of this)." Most responses and interviews commented on frustration concerning the lack of useful documented guidance. Additional responses are paraphrased or quoted below:

- I am not aware of any policies that adequately address reliability
- You've hit the nail on the head with identifying the vague nature of what is currently in print

- Due to acquisition reform, the Government has steered aware from military specs and standards. Also, this makes it difficult to identify which regulations and guidance for reliability are applicable at any time.

Summary: According to the responses, the acquisition community either has little guidance or is not aware of guidance concerning reliability management. Additionally, much of the guidance is very broad scoped, providing little detail as to specific reliability actions to be taken in the acquisition process.

D. DETERMINING AND DOCUMENTING RELIABILITY REQUIREMENTS

Purpose of Theme: The next group of questions deals with reliability in the context of inputs and procedures of the requirements generation process. The purpose of the questions was to determine and assess whether a reasonable and cooperative process exists between the Combat Developer and the Materiel Developer, if reliability requirements were arbitrarily set or not, if the original reliability requirement was documented, and if so, where is it documented, what was the reliability requirement, and in what terms was it identified.

1. Influencing Realistic Reliability Requirements

A common criticism of the acquisition process is that system requirements are not adequately defined or are often unrealistic. The challenge is to address the reliability requirements in terms of the users' operational mission needs and success under given conditions, with defined mission profiles, environments, and durations (Ryan, p. 47).

The following questions and corresponding data address the Materiel Developer's ability to influence system reliability requirements, and the level and terms at which the requirements were set. Participants were asked, if "the PMO, as a representative of the Materiel Developer, was able to influence incorporation of realistic reliability requirements into the process." They were also asked, "what the documented reliability or availability requirement was, and in what terms it was measured (i.e., MTBF, MTBM, A_o, MTBSA, MTBOMF, MTBEFF, MTBOMA, MTBMAT, etc.)".

Survey Responses: In nearly all cases, materiel developer representatives were able to provide input for establishing reliability requirements.

Ability to Influence Reliability Requirement	Percentage of Programs Examined
YES	78 %
NO	0 %
NOT SURE	22 %

Table 4.2. Influence on the Requirements Generation Process.

The terms in which reliability requirements were identified varied from program to program. Respondents indicated the documentation of requirements in the form of: Mean Miles Between Failure (MMBF), Mean Miles Between Operational Mission Failure (MMBOMF), Mean Time Between Operational Mission Failure (MTBOMF), Operational Availability (A_o), Mean Time Between Unscheduled Maintenance (MTBUM), and Mean Time Between Failure (MTBF).

Additional related responses concerning reliability requirements are paraphrased below:

- Contractors are in business to provide the Government the products and services we request. If they fail to do so, they go out of business. The question then becomes, are we asking for what we really want in clear and concise terms? When a program fails, too many people in this business affix blame to the contractors. Instead, I believe that the Government is ultimately accountable to the taxpayers. Did we ask for what we needed? Did we select the right contractor to do the job? Did we provide adequate support and oversight to the project? I realize that very few officials in Government are willing to ask such tough questions.
- MCCDC has the responsibility of creating the requirements, but the PM office comments on the requirements and their rational with MCCDC
- In order to determine user reliability requirements, emphasis must be placed on understanding the user's system readiness and mission performance requirements; and translating them into system requirements that can be designed, implemented, and verified

Summary: According to the responses, it appears that programs actively participate with the Combat Developer to determine the requirements, including those requirements relating specifically to reliability as part of the RAM determination process.

Thus, it may be assumed that a reasonable and cooperative process exists between the Combat Developer, Materiel Developer, and the user representative.

A review of the terms in which the reliability requirement is identified varies from program to program, indicating that there is not a standard operational terminology in which reliability must be expressed. While this likely allows for flexibility, there must be an agreement and understanding between the Government and contractor of those terms, as further sections will indicate.

2. Reliability as a KPP in the ORD

As the survey responses indicated in the previous section, most programs had documented reliability requirements, while identifying the specific terms (MTBF, MTBM, etc.) used in defining requirement. It then becomes useful to discover where the requirements are documented.

The author hoped to ascertain the relative importance of reliability with respect to other performance parameters. Participants were asked if reliability requirements were identified as Key Performance Parameters (KPP) in the Operational Requirements Document (ORD). Additionally, they were asked whether the requirement was in an objective and quantifiable form that contractors and the Government could easily agree upon.

<u>Survey Responses</u>: Only two responses indicated the use of a reliability requirement as a KPP – one of which had a sister service as the executive agent, and the other was the AAAV, which is the only system still under development from which survey responses were collected. Meanwhile, none of the remaining legacy programs examined included reliability as a KPP. Some responses indicated that their current program staff could not locate the ORD due to the time that has passed and the turnover of personnel. Additional related responses were:

- RAM requirements are usually not KPPs. So when there are cost or schedule overruns, these are the first to take a hit.
- Reliability and maintainability, along with performance, should act as equal partners in the requirements generation process
- Test to requirements in the ORD. If reliability is not a KPP in the ORD, it gets pushed aside due to other requirements precedence

- There seems to be a huge traceability problem. We couldn't even find the (undisclosed program name) ORD until (undisclosed analyst) called an old friend at the contractor who had kept a copy.

Summary: While reliability requirements were typically not identified as KPPs, programs agreed that reliability was an important priority that received varying degrees of attention.

As previously mentioned, all of the systems examined were legacy systems with the exception of the AAAV. Interestingly, the newest system examined, which is still under development, has designated reliability as a KPP. In fact, the AAAV has a very specific MTBOMF threshold as a KPP for the Milestone C decision. Additionally, to ensure that the requirement is in an objective and quantifiable term that the contractor and the Government can agree upon, the AAAV contractor was "given the Failure Definition and Scoring Criteria which was the basis of determining whether a failure was an operational mission failure."

E. CONTRACTING AND INCENTIVIZING FOR RELIABILITY

Purpose of Theme: The questions and corresponding survey responses in this section relate to the role of reliability in the source selection and contracting process. The overall intent of this series of questions was to determine how and to what extent reliability requirements were developed into contractual agreements.

1. Reliability as a Source Selection Factor

Programs were queried as to whether reliability was included as a factor in source selection.

Survey Responses: With the exception of the AAAV, the program respondents replied that either reliability was not a factor in source selection or they were not certain if reliability was a factor in source selection due to the time that had passed since the program was originally contracted and the lack of documentation in the PM offices.

Summary: While reliability was not a factor in source selection for the legacy systems examined, some respondents gave the impression best put by one individual, "Reliability, with its impact on O&S costs, *should* receive critical attention in the market investigation, solicitation, and source selection process. Unfortunately, I believe this is typically not the case."

2. Reliability Requirements in Contracts

The second contract related question inquired as to how operational reliability requirements in the ORD were translated into contractual requirements.

Survey Responses: Roughly two-thirds of the participating survey respondents indicated the ORD paragraphs relative to reliability were restated in the Statement of Work or performance specifications, indicating that the contract requirement was very similar to the ORD requirement. One of the oldest systems, which has exceeded its intended life cycle by over a decade and a half due to extensive upgrades and Depot Level Maintenance, indicated that comprehensive reliability requirements were not adequately stated in the original contract. Conversely, the AAAV sets precedence for future systems by applying "additional levels of reliability to the contract as the performance specifications (in the contract) set the bar a little higher than the ORD." Additional related responses concerning the contractual reliability requirements are provided:

- While predicted reliability typically comes form contractor claims, we need some confidence level that it is a good system of merit for predicted reliability. We must contract with the Prime (contractor) for a commitment to some target A_o.
- We need to make readiness targets contract items
- It would require contract changes to hold contractors accountable to their estimates
- Reliability objectives should be translated into quantifiable and verifiable contractual terms and allocated through the system design hierarchy
- Contractual requirements should be traceable to operational requirements and capable of verification
- We should adopt the null hypothesis that states the MTBF is not what the contractor claims, but rather what the contractor proves

Summary: In terms of translating user operational requirements to contractual requirements, all but one of the legacy systems examined indicated that the contractual requirement was very similar to the ORD requirement, and ORD paragraphs relative to reliability were simply restated in the SOW or specifications. The remaining legacy system stated that the comprehensive reliability requirements were not adequately stated

in the original contract. Conversely, the AAAV applied additional levels of reliability to the contract.

3. Contracting Incentives for Reliability

The use of meaningful contract incentives for achieving predetermined reliability performance is a method to encourage contractors. Survey participants were questioned if incentives that are specifically tied to achieving system reliability performance requirements were employed in their programs' contracts, and if so, did the incentives achieve their desired effects.

Survey Responses: The respondents representing the legacy systems indicated that contract incentives were not utilized for the *original* purchases of their systems. However, the AAAV program staff cited the use of a Cost Plus Award Fee (CPAF) contract, and further indicated that reliability has been used as one of the award fee criterion on numerous occasions thus far. Additional comments are provided below:

- If a contractor does not meet the predetermined reliability goals, it should be considered a latent defect
- We must tie the contractor to LCC through reliability. In other words, we must reduce life cycle support costs through reliability warranties and incentives
- Incentives should be created to reward for good systems in terms of logistics

Summary: Of the legacy systems examined, there was no apparent use of contract incentives for reliability achievement.

F. RELIABILITY TESTING

Purpose of Theme: Test and evaluation activities are a critical part of every program as they serve to aid in the development of a system and to verify that the system meets specified standards. The questions in the proceeding sections are concerned with: 1) the adequacy of time and funding allotted for reliability testing during developmental testing, 2) general agreement and common understanding on measures to determine reliability performance during testing, and 3) the use of IOT&E entrance criteria relative to reliability.

1. Resources: Time and Funding Constraints

In an attempt to achieve program objectives, program management requires making trade-offs in terms of cost, schedule, performance, and supportability. Programs were queried as to whether the amount of time and funding allotted for reliability testing during DT&E was sufficient.

Survey Responses: All but one program indicated an insufficient amount of time and funding allotted for reliability testing during developmental testing. However, this is not surprising in the acquisition world where program offices continuously are forced to conduct trade-offs. One program summarized the constrained resource situation by stating, "there is never enough time or money because the more time and money (available), the more failures that can be uncovered and corrected."

Summary: A common perspective relayed by the program offices is a lack of time and money to conduct adequate levels of reliability testing which are needed to achieve a substantial confidence level of the system reliability. In fact, data from the first survey question indicated that too much pressure to field systems quickly and too much pressure to field systems cheaply were respectively the second and ninth ranked inhibitors to effective reliability management.

2. Agreement on Reliability Measures for Tests

The concept of reliability is often used without precise definition, while the terminology is non-standard throughout the logistics community and tends to depend on the system being developed. However, while creating DoD requirements documentation, contract specifications, and test documentation, it is very important that all main concepts are addressed in an unambiguous way so that all parties involved (to include the user, combat developer, materiel developer, PM, contractor, and tester) understand the terms. Survey participants were asked if the user, contractor, tester, and PM all agreed upon the method used to determine reliability performance during testing.

Survey Responses: One of the legacy programs answered affirmatively, stating that the agreed upon method could be found in the TEMP. The remaining systems indicated that they were uncertain if such an agreement had been made amongst all parties. The numerous "not certain" responses are likely a result of the time that had

lapsed, the turnover of personnel, and the loss of documentation since the test phases had occurred years prior.

3. Testing to Determine Reliability Requirements Conformance

a. Initial Operational Test & Evaluation (IOT&E) Entrance Criteria

Operational Test and Evaluation is the final test conducted prior to the decision on whether the system will proceed with full rate production. Given the significance of this program gate, entrance criteria, relative to reliability, is often established to ensure that the system is prepared for Initial Operational Test and Evaluation. Meeting reliability entrance criteria commonly involves testing reliability in Developmental Testing activities and involves validating required reliability levels. Such entrance criteria are most often required by the independent testing organization.

Survey participants were asked if their respective programs had specific IOT&E criteria relative to reliability.

Survey Responses: A significant majority of the responding programs had IOT&E entrance criteria relative to reliability. Furthermore, most criteria were established in very specific terms, such as MTBOMF. Notably, the AAAV program indicated that the Milestone C criteria, which allows the program to build Low Rate Initial Production (LRIP) vehicles for IOT&E, was to "demonstrate system reliability within the Growth Curve at 80% confidence through a mix of test data and analysis." On the other hand, one program indicated that IOT&E entrance criteria were not used by the sister service executive agent, and one program was uncertain if entrance criteria were utilized.

b. Reliability Demonstration During Developmental and Operational Testing

Programs were asked to what level were their systems' ORD reliability requirements demonstrated during developmental testing, operational testing, and during sustainment. Additionally, programs were asked to what level were the contractors' reliability estimates demonstrated during developmental testing, operational testing, and sustainment. By posing such questions, the author intended to gain a better understanding of the required level of reliability demonstration prior to the program

proceeding, whether reliability requirements and contractor estimates were sufficiently realistic to be achieved, and whether there was a correlation between success/failure in DT&E, OT&E, and sustaiment with respect to reliability performance. Survey test related responses are provided below:

- We've found they (PMOs) don't have much documentation from the DT&E phase of programs. We've had more success finding OT&E reports from MCOTEA since these are Government-run and usually archived by DTIC or service libraries.
- The DT&E reports were probably submitted to PM staff and ended up taken or lost when those people moved on
- It is during T&E that we (Government) must validate the contractor's estimates. Under- or over-estimating reliability will cause limited funds to be allocated unwisely
- Once the contractor submits their RAM estimate, it becomes the Government's estimate if we accept it. Therefore, it's up to us to become involved in this process and to conduct independent testing as necessary to verify such estimates.
- Demonstration of required reliability performance levels prior to system fielding is a challenge
- Estimated or measured reliability should be used to evaluate the design
- Achievement of contractual requirements should be verified through a combination of engineering analysis and test results
- Test to (the) requirements in the ORD
- Determination of contractual compliance based on engineering analysis without supporting test data can lead to erroneous conclusions
- We must conduct Logistics Test & Evaluation (LT&E) early and throughout the DT&E, allowing program office personnel to determine what needs to be adjusted to provide the required system support throughout the program's life cycle

Survey Results: Qualitative responses to this question were limited. None of the participating programs were able to identify the level to which the contractors' estimates were demonstrated (during testing phases or sustainment) due to the fact that contractor estimates were not retained.

Additionally, in some cases, the ORD could not be found, meaning the original reliability requirement was not retained either.

Lastly, most programs indicated that achieved field reliability data compiled during the sustainment phases of the respective systems is suspect to error, making the comparison of such data with the contractor estimates and original ORD requirements (when available) questionable. The proceeding section is devoted to such issues and concerns.

G. COMPARING AND ASSESSING REQUIRED, ESTIMATED, AND ACHIEVED RELIABILITY

Purpose of Theme: Programs that have carefully planned and executed reliability management techniques will benefit, in the way of decreased life cycle costs and increased operational availability, during sustainment of the system. However, reliability performance of a system should be continually assessed throughout its lifecycle. Programs often assume reliability to be what the contractor states it to be instead of determining progress and compliance with reliability estimates and requirements throughout the lifecycle sustainment phase.

This section summarizes previous questions by compiling and comparing survey responses concerning ORD reliability requirements, contractor reliability estimates, and achieved reliability. The data is intended to determine whether PMOs and the logistics community are adequately engaged in tracking and improving system reliability through a systematic process of collecting reliability trend data.

1. Maintaining Original Contractor Estimates

Participants were queried as to whether or not the contractor reliability estimate was documented, and if so, where was it documented, who retains the documentation, what was the estimate, and in what terms was it measured (i.e., MTBF, MTBM, MTBOMF, MMBF, A_o, etc.).

Survey Responses: All responding programs indicated that either the contractor reliability estimates were not documented or the documentation was not retained. One respondent stated that the estimates were not retained because the "program was too old". Other related responses are provided:

- I highly suspect you will have to go to each PM's office in an attempt to locate this information (ORD, contract, reliability rqmt, reliability estimate, and achieved reliability)

- Where will you get copies of the contractors' RAM estimates? Does anyone retain these documents after the system is fielded?
- Once the contractor submits their RAM estimate, it becomes the Government's estimate if we accept it.
- . . . we (the Government) must validate the contractor's (reliability) estimate.
- Unfortunately, there is not an annual inspection that checks whether or not they are maintaining the data and information.

2. Collection and Computation of Achieved Field Reliability

Calculation of system reliability that is being achieved in the field is necessary in order to determine whether the mean time between failures is increasing, decreasing, or remaining constant with age. In other words, such data analysis and assessment of reliability performance help to determine if equipment is in the "wear-out" phase of its life cycle and at the end of its economic useful life.

Participating program representatives were asked whether the achieved reliability of their programs had been computed, and if so, what was the overall achieved reliability and in what form was it calculated. It is important to recall from Chapter II that there are numerous forms of measurements that relate to reliability achievement, to include MTBF, MTBM, MTBOMF, MMBF, A_o and others. Table 4.3, in the next section provides the results. Additionally, various personnel provided the remarks below:

- USMC maintenance management systems record maintenance activities and not system failures, (which are required to calculate MTBF), while the systems do not distinguish between preventative and corrective maintenance activities
- Rather than computing 'failure rates,' we are focusing instead on 'maintenance rates' because our AIS systems do not directly record failures; MIMMS/ATLASS records maintenance events. We believe that maintenance rate analysis is a feasible surrogate for traditional failure rate analysis; based on existing data sources, that's probably the best we can do. Even then, we've run into significant obstacles and data quality issues with MIMMS.
- Also, any metric based on operational usage data won't work. The meter readings in MIMMS are inconsistent and inaccurate (e.g., odometer reading = 999999, mixing engine hours and odometer miles, etc.).
- Utilization data is not consistent
- It is hard to distinguish between corrective and preventive maintenance

Summary: Lack of necessary data and related weaknesses in the Marine Corps maintenance management data systems prevent the calculation of MTBF. Specifically, operational usage data is required to calculate failure rate, a key indicator of reliability performance. Thus, the maintenance rate has often been used as a substitute for failure rate, but when utilizing MTBM in place of MTBF, it is important to recall that MTBM does not distinguish between preventive and corrective maintenance activities. Furthermore, issues with data quality derived from maintenance management systems also make the calculation of MTBM skeptical. Thus, many professionals believe that the next best calculation is the R-rating or readiness rating, known as the SORTS equipment condition rating, calculated as follows as per MCBul 3000:

$$R = \frac{QtyPossessed - QtyNotMissionCapable}{QtyPossessed}$$

The R-rating basically provides a snapshot of operational availability, for which the calculation is shown below:

$$A_o = \frac{uptime}{uptime + dowtime} = \frac{MTBM}{MTBM + MDT} = \frac{\overbrace{OT + ST}^{UPTIME}}{\underbrace{OT + ST}_{UPTIME} + \underbrace{ALDT + CMT + PMT}_{DOWNTIME}}$$

The calculation of operational availability is affected by inhibiting factors in the logistics system such as administrative delay time, order ship time delays, and delays in corrective and preventive maintenance. Additionally, standby time (ST) is not recorded and distinguished from operating time (OT). Lastly, the data is extracted from disparate sources (MIMMS and ATLASS).

3. Comparing Required Reliability, Estimated Reliability, and Achieved Reliability

It is important to have a systematic process in place for collecting and comparing reliability data for several reasons. The Marine Corps must be able to calculate and compare the reliability that is being achieved in the field during post-production with the required and estimated reliability in order to determine contactor compliance, successfully hold contractors to their estimates, and determine if the user reliability requirement is met.

The data from the questions in the previous sections were combined in an attempt to determine the "reliability gap" of the legacy systems, or the difference between the required reliability, contrac tor reliability estimates, and achieved reliability. Additionally, programs were asked what organization(s), if any, have compared and assessed actual achieved reliability of fielded systems to the original requirements and contractors' estimates.

Survey Responses: All of the legacy system respondents stated that no organization, internal or external to their programs, has formally or informally determined the "reliability gap" for the respective systems up to this point in time. One program did note that MCCDC is concurrently conducting a similarly related study entitled "Sustainment Consequences of Acquisition Decisions", which is sponsored by MARCORSYSCOM.

Table 4.3 provides a comparison of three sample programs' reliability requirements, contractor reliability estimates, and achieved reliability, as well as participants' personal perspectives when provided.

	Program 1	**Program 2**	**Program 3**
Reliability Requirement	43.5 MTBOMF threshold	600 MMBF (not delineated in the ORD)	Not Known
Contractor Reliability Estimate	*"Estimate not documented"*	*"Estimate not retained; program is too old"*	*"Don't know if documented; not retained"*
(Post-Production) Achieved Reliability	89 MTBOMF; *"data is suspect"*	*"Not certain. The Marine Corps does not do a good job capturing this data"*	*" > 80% Readiness "*

Table 4.3. Reliability Gap.

Additional comments concerning the computation and comparison of required, estimated, and achieved reliability are provided below:

- Traditional T&E RAM metrics are not supported by our maintenance data sources so how will you make a valid comparison between contractor RAM estimates and actual data?
- Our experience here (Studies and Analysis branch) is that data is not easy to come by
- Reliability focus should not end with OT&E. Once the system is fielded, reliability should become a permanent part of the PM's and Logistics Management Specialist's (LMS) sustainment activities. Critical system and components must be identified where low reliability rates are hampering mission accomplishment.
- Currently using the wrong metrics

Summary: It is well known that "you can't manage what you don't measure," and in general, responses indicate that there is a lack of a systematic process for collecting reliability trend data beyond readiness ratings. Furthermore, what data that does exist is suspect to error and corruption as a result of the current maintenance management automated information systems.

There was also a consensus that traditional test and evaluation RAM metrics are not supported by maintenance management data systems. One may recall that this was voted as the top rated inhibitor to effective reliability management, according to the responses from the first question of the survey.

a. MTBM Computation

A study was completed on 08 June 2002 by Captain Jake Enholm in an attempt to formulate a methodology for determining systemic MTBM and equipment parts' (NSNs) failure rates using current warehoused maintenance management data drawn from MIMMS/ATLASS II/SASSY data fields. In the calculations used in this study, MTBF and MTBM periods were combined as the model used both preventive and corrective maintenance actions combined. The results of the study indicated that it is sometimes possible to calculate a sample mean or median time between maintenance/failure for certain equipment in the Marine Corps. However, the study indicated that the accuracy of the analysis is suspect to weaknesses in the Marine Corps'

maintenance management data systems. A full version of the study is available in Appendix C.

b. Depot Level Maintenance Program Effects

Due to the age of the respective systems, concerns about increasing failure rates and increasing costs to maintain, and in some cases, declining readiness trends, some of the systems examined have undergone Depot Level Maintenance (DLM) programs such as "Service Life Extension Program" (SLEP) or "Inspection and Repair Only As Necessary" (IROAN). Programs such as these, which modify, upgrade, or change the designs of the systems, as well as overhaul major components, obviously affect the reliability of the systems and skew the data that is attempting to be compared. Therefore, to take this factor into consideration, survey participants were specifically asked whether their programs had undergone and type of Depot Level Maintenance programs and what the effect was on reliability. Answers varied greatly. Some programs that had undergone DLM programs claimed drastic changes in reliability performance while others claimed there was no significant change following completion of the maintenance activities. Another respondent noted that his program was scheduled for mid-life rebuild, but the action was never carried out due to funding constraints.

c. Reliability Growth Programs

Reliability growth is the improvement in a reliability parameter over a period of time resulting from changes in product design or the manufacturing process. A structured reliability growth program is typically created with specific interim reliability goals and test events. As the system design matures, testing is performed at designated intervals to identify actual or potential sources of failure.

Managing reliability growth requires systematic planning for reliability performance achievement as a function of time and other resources. This involves controlling the ongoing rate of achievement by reallocation of resources based on comparisons required, planned, estimated, and assessed reliability values (Ryan, p. 42). Formal reliability growth programs serve to not only ascertain requirement compliance, but to also identify potential problems early in development.

Survey participants were asked whether their programs incorporated a formal reliability growth program. With the exception of the AAAV program, still under

development, none of the programs examined had a formal reliability growth program in place. However, there was a general agreement that the focus should be on discovering design flaws early and fixing them as early as possible to avoid potential cost overruns in the future of the program.

H. CHAPTER SUMMARY

This chapter presents the methodology used and the data gathered from the survey, interviews, and emails. Professionals within the Marine Corps acquisition community directly contributed by providing information about their programs, experiences, and perspectives with respect to reliability management. The data was organized into five major themes: 1) management approach to reliability, 2) determining and documenting reliability requirements, 3) contracting and incentivizing for reliability, 4) reliability testing, and 5) comparing and assessing required, estimated, and achieved field reliability.

It should be noted that the survey responses were from individuals that inherited the programs long after the systems were developed and fielded. Consequently, many of the responses were a result of a lack of documentation confirming actions taken during development and not necessarily a result of a lack of action on the part of the original PM staff.

The next chapter provides an organized analysis of the data presented in this chapter. The author focuses on common inhibitors, enablers, issues, and risks associated with effective reliability management while discussing mitigation techniques.

V. PROGRAM RELIABILITY ANALYSIS AND LESSONS LEARNED

A. INTRODUCTION

This chapter provides an analysis and assessment of the common reliability management issues faced by Marine Corps Program Management Offices. The research results focus on the perspectives and opinions of acquisition personnel, as attained from the survey responses, and do not specifically address technology driven reliability problems. The analysis follows the format of the data presented in the previous chapter, organized around the five reliability management themes, developed for the purpose of this thesis, and listed below:

- Management Approach to Reliability
- Determining and Documenting Reliability Requirements
- Contracting and Incentivizing for Reliability
- Reliability Testing
- Comparing and Assessing Required, Estimated, and Achieved Reliability

While the research is limited to selected legacy principle end items, it is logical that many of the challenges, issues, and potential solutions correlate to other end items in the Marine Corps acquisition process or currently in operational use.

B. ANALYSIS OF RELIABILITY MANAGEMENT ISSUES

1. Management Approach to Reliability

a. Factors Contributing to Reliability Performance Problems

Weapon systems often fall short of the desired level of reliability planners and developers originally planned to achieve. While increased system complexity and harsh environmental and operational conditions likely contribute to the challenges associated with achieving reliability requirements, the researcher observes that a large portion of performance problems can be directly linked to management of reliability factors. The following survey responses cite the top five reliability issues in order merit ranking as viewed by acquisition professionals participating in this research:

- Wrong Metrics - Traditional T&E RAM metrics are not supported by USMC maintenance data sources, and programs are unable to make a valid comparison between RAM requirements and estimates with achieved

field data. How can a program manage something that is not adequately measured?

- Schedule Goals Outweigh Reliability – too much pressure to field systems rapidly
- Need more qualified reliability personnel in Program Offices
- Unrealistic Requirements - unrealistic reliability requirements with inadequate rationale; there seems to be a disconnect between user, materiel developer, and combat developer thoughts on realistic requirements
- Poor Reliability Planning and Growth Planning – reliability growth is not properly utilized as a tool to reduce reliability related issues upfront

b. Reliability Roles and Responsibilities

Among those systems examined, there was no consistent managerial approach concerning who was delegated responsibility for reliability activities. However, all but one program cited at least one individual who was primarily responsible for reliability as survey respondents identified Logistics Team Leaders, Project Team Leaders, Supportability Team Leaders, or Reliability IPTs.

As one former PM noted, PMs often manage by exception and without a specific problem or issue, reliability and the other engineering disciplines are managed through empowerment of technical experts. In this sense, it is interpreted that PMs depend upon outside reliability competency for matrix support. The reliability experts typically provide input on the specific reliability activities and where they should be implemented. How such an approach is incorporated into a program is dependent upon available funding, as well as the PM's judgment based on cost, schedule, performance, and supportability considerations.

Survey respondents identified the need for more qualified reliability personnel in program offices as the third top inhibitor to effective reliability management. By assigning a permanent reliability engineer or staff, just as the AAAV program has done, adequate technical expertise is available to the Program Manager. This would allow logistics engineers to partner with their counterparts in reliability engineering to collectively define and allocate reliability requirements affecting logistics. The duo must defend the logistics support concepts and supportability design requirements that they

propose, not only from the logistics community's perspective, but also from the engineering point of view.

The author believes that assigning an individual or team, such as a formally chartered reliability IPT, as the central authority on reliability activities ensures there is a reliability advocate that can defend related issues and identify concerns during the numerous trade-off analyses and discussions.

c. Documenting a Program's Reliability Approach

The fifth ranked inhibitor to effective reliability management, as derived from the survey, was poor reliability planning and growth planning. Consequently, half of the programs reviewed indicated that there was no formal reliability management plan while the other half simply relied on the contract SOW or TEMP to address the methodologies and plans for measuring and achieving reliability. Again, the exception was the AAAV program office, which uses a FRACAS database to formally document its reliability program plan.

In order to provide visibility into the management and activities of those parties responsible (Government and contractor) for the reliability progress within a program, there should be definitive documentation on all reliability activities, functions, processes, test strategies, measurement/metrics, data collection, resources and timelines required to ensure reliability system maturation. Specifically, Reliability Program Plans (RPPs) can serve as a comprehensive document detailing all of the actions, functions, resources and timelines related to reliability. Such plans would especially prove invaluable if an initiative is implemented that would make predicted and demonstrated reliability a mandatory component of the acquisition world at each phase of the acquisition cycle.

d. Tools Used in Evaluating Potential Failures

Proactive reliability management early in the lifecycle of a system is typically more cost effective than coping with schedule delays and unanticipated costs of failing a test later, forcing costly redesign and additional testing to demonstrate that the problem is corrected. There are numerous test and design tools available to program offices and contractors that help to ensure reliability is "designed in" early in the program, but it is up to the program management to ensure such opportunities are

exploited. The risk mitigation techniques consist of testing, engineering, and other technical methods used to determine and evaluate potential system failures and their causes. However, the extent to which the legacy programs failed to utilize the reliability risk mitigation activities was surprising. Aside from developmental and operational testing, programs generally indicated use of only one of the following techniques: Environmental Stress Screening (ESS), reliability modeling, FMECA, Reliability Development/Growth Test (RD/GT), or FRACAS. No (legacy) programs were aware of the use of reliability allocation, fault tree analysis, probabilistic failure assessment, reliability qualification test, PFMEA, Weibull analysis, physics of failure, or a parts control program. The AAAV program, currently under development, seems to be setting precedence for future weapons systems in terms of reliability management, as it was the only system examined which utilized all of the identified risk mitigation techniques identified by the survey.

Many program representatives were either not aware of the specific techniques utilized to ensure reliability was "built-in," or the original staffs did not use the available tools. However, there was a common consensus to test early and often, and use knowledge of reliability growth to implement corrective action. All PMOs reported using some form of failure analysis as an integral part of the design process, and there was a consensus that the use of such tools, which incorporate reliability prediction and achievement into system design, was beneficial.

In most cases, the survey respondents were not the original PMO staff, and the respondents may have been aware of which techniques were utilized only by reviewing any existing documentation that was retained before their arrival. Often, documentation from the original staff or the contractor was no longer available, and thus, the assumption that the legacy systems did not take advantage of the reliability analysis tools may be invalid. In reality, many of the programs may have utilized the tools more than indicated in the survey, and the respondents were not aware of the previous staffs' or contractors' actions.

e. Existing Policy, Guidance, and Regulations on Reliability

The acquisition community either has little guidance or is not aware of guidance concerning reliability management. Survey responses indicate that the little

existing guidance is very broadly scoped, providing minimal detail as to specific reliability actions to be taken in the acquisition process. For example, the DoD 5000.2-R states that the "PM shall establish RAM activities early in the acquisition cycle." Additionally, the amount of mandatory guidance is minimal and has further decreased in recent years, due to acquisition reform initiatives, and the applicability of discretionary guidance seems to be somewhat confusing to the acquisition community. Ironically, the DoD 5000 series was cancelled, while the author was collecting research for this thesis, because its guidance was deemed too restrictive in nature.

The acquisition workforce, responsible for reliability activities, appears to need enforceable and precisely delineated criteria, standards, and procedures to guide it in the effective management of reliability.

2. Determining and Documenting Reliability Requirements

a. Influencing Realistic Reliability Requirements

According to the survey responses, which indicate the materiel developer was able to provide input for establishing reliability requirements in nearly all programs, it appears that programs actively participate with the Combat Developer to determine the requirements relating to reliability. Ironically, the fourth top rated factor contributing to reliability management problems, as derived from the first survey question, was that PMOs were faced with "unrealistic reliability requirements with inadequate rationale." This indicates that there is a disconnect between the user, materiel developer, and combat developer with regard to the perspectives of realistic requirements.

The respondents indicated the opportunity is available to influence reliability requirements generation. It is essential that logistics and reliability expertise be involved in requirements generation, on behalf of the PM, in this early stage of program development. The extent to which the level of influence is effective is largely dependent upon their level of expertise and involvement.

A review of the terms in which the reliability requirement is identified varies from program to program, indicating that there is not a standard operational terminology in which reliability must be expressed. While this likely allows for

flexibility, there must be an agreement and understanding between the Government and contractor of those terms, as examined in upcoming sections.

b. Reliability as a KPP in the ORD

While reliability requirements were not identified as KPPs, programs agreed that reliability was an important priority that received attention in the ORD. According to DoD 5000.2-R, reliability requirements are to address "mission reliability" and "logistics reliability," implying that ORD requirements should focus on measures related to mission completion, such as operational availability. Appropriately, all of the systems examined had specific MTBOMF or MMBF requirements.

The AAAV, which is still under development, is the only program that indicated the use of reliability as a KPP. In fact, the AAAV has a very specific MTBOMF threshold as a KPP for the Milestone C decision. To ensure that the requirement is in an objective and quantifiable term that the contractor and the Government can agree upon, according to the reliability survey responses, the AAAV contractor was "given the Failure Definition and Scoring Criteria which was the basis of determining whether a failure was an operational mission failure."

One assumption for the traditional systems not designating a definitive reliability KPP is that doing so would have compromised the flexibility and trade-off range available to PMs in a time where cost, schedule, and performance were the priority. However, it is generally agreed, in theory, that reliability and maintainability, along with performance, should act as equal partners in today's requirements generation process. This is logical as reliability and maintainability contribute to combat power generation and are not severable from system performance. If reliability is not a KPP in the ORD, it simply gets pushed aside due to other requirements precedence.

c. Reliability as a Source Selection Factor

With the exception of the AAAV, the program respondents replied that either reliability was not a factor in source selection or they were not certain if reliability was a factor in source selection due to the time that had passed since the program was originally contracted and the lack of documentation in the PM offices. While reliability was not a source selection factor, some respondents gave the impression that, "Reliability, with its impact on O&S costs, *should* receive critical attention in the market

investigation, solicitation, and source selection process." Reliability is a logical key source selection criterion to contribute to future equipment readiness improvements and to ensure adequate logistics weight in source selection.

3. Contracting for Reliability

The concept of reliability is often utilized without precise definition, while the terminology is non-standard throughout the logistics community and tends to depend on the system being developed. However, while creating DoD requirements documentation, contract specifications, and test documentation, it is very important that all main concepts are addressed in an unambiguous way so that all parties involved (to include the user, combat developer, materiel developer, PM, contractor, and tester) understand the terms.

A common problem occurs during the translation of operational reliability requirements into contractual reliability requirements, as they typically are expressed in different terms. Operational reliability parameters, as derived by the user and Combat Developer, are often in terms of operational availability or mission duration needs. The Materiel Developer takes these parameters and allocates them to technical reliabilities of the system in the terms of MTBM, MTBOMF, or MTBF, traditionally the common parameters of reliability used for contractual purposes. The focus for the PM is to ensure the contractual reliability of the system, as measured in controlled test conditions, supports the dynamic and unpredictable environment in which operational availability is measured. The challenge for PMs remains in creating a definitive correlation between operational and contractual reliability, one that positively indicates anticipated system reliability performance.

In order to achieve the reliability requirement specified in the ORD, additional levels of increased reliability may be added to the contract, just as the AAAV has done. This helps to account for the environmental and operational differences imposed during fleet operations. However, roughly two-thirds of the participating survey respondents indicated that the ORD paragraphs relating to reliability were simply restated in the Statement of Work or performance specifications, indicating that the contract requirement was very similar to the ORD requirement and open to interpretation.

The contractor and designer must consider the risks of field maintenance and minimize the characteristics of the design that are susceptible to operationally induced reliability deterioration. Likewise, contractor reliability predictions should be based on realistic operational projections for degradation. The operation and maintenance of equipment in the field can induce these effects by stressing systems beyond predicted levels. Operational contributors to such overstresses include neglect, unfamiliarity, carelessness, and mission constraints. Maintenance actions can also induce defects in otherwise satisfactory assemblies; foreign objects introduced, fasteners improperly engaged, contaminants introduced, improper part replacement, improper lubricants, etc. The contract provisions should attempt to account for all elements contributing to the combined failure rate and provide the Government with a confidence interval for a predetermined readiness performance in the form of operational availability. Ultimately, performance specifications should include an inherent reliability goal, and when such goals are not achieved, it should be considered a latent defect.

4. Reliability Testing

a. Resource Constraints

A common perspective expressed by the program offices is a lack of time and money to conduct adequate levels of reliability testing, which are needed to achieve a substantial confidence level of the system reliability. In fact, data from the first survey question indicated that there is too much pressure to field systems quickly and too much pressure to field systems cheaply, which were, respectively, the second and ninth ranked inhibitors to effective reliability management. However, this is not surprising in the acquisition world where program offices continuously conduct trade-off analyses while competing for constrained resources in a politically affected environment.

Funding and time constraints create trade-offs between reliability improvements and performance improvements. In reality, system performance improvements are often made at the expense of potential reliability enhancements. Such decreased emphasis on reliability resources typically increase life cycle costs as the acquisition community and those guiding it must acknowledge that funding not spent on reliability optimization during development will be spent multiple times over during operations and support.

Trading off reliability for another performance enhancement is not only costly in terms of Total Ownership Costs, but may actually make the system less combat effective as maintenance workload increases, adversely affecting system availability.

b. Testing to Determine Reliability Performance

A major focus for the PM is to ensure the contractual reliability of the system, as measured in controlled tests, is adequate for the dynamic and unpredictable operational environment in which the system is intended to operate. Without adequate Government testing, which is to provide a substantial confidence level of system reliability, DoD is often forced to utilize erroneous contractor or manufacturer estimates of reliability performance as a basis for logistics supportability decisions. Under- or over-estimating reliability will cause limited funds to be allocated unwisely. For example, inaccurate reliability estimates can potentially have devastating effects in terms of spare parts availability, the amount and level of mechanic training, repair facilities infrastructure, system operational availability, and increased life cycle costs. The contractor or manufacturer claims of reliability must be proven through independent testing, and claims should be considered unsubstantiated until tested. In other words, DoD must adopt the null hypothesis that the reliability is not what the contractor claims, but rather, what the contractor proves. To do so, the Government must validate the contractor's estimates. Once the contractor submits their RAM estimate, it becomes the Government's estimate only if they accept it. Therefore, it is up to DoD to become involved in this process and to conduct independent testing as necessary to verify such estimates.

c. Political and Cultural Barriers Affecting Testing

Program Managers are evaluated on procurement cost, schedule, and system performance, in accordance with Defense Acquisition Executive Summary, versus supportability, in the form of a target operational availability or life cycle cost. Consequently, PMs have traditionally had the incentive to reduce up-front procurement costs and field systems rapidly, often accomplished through reduced research, development, test, and evaluation. The effects of such incentives directly contribute to reduced reliability performance, decreased readiness, and increased life cycle costs. If the PMs, the prime contractor, and all members of the IPTs were evaluated on readiness

performance, and incentives were in place to reward for reliable and supportable systems, the effect would likely be an increased focus on RDT&E activities associated with reliability achievement, which would ultimately decrease life cycle costs while increasing operational availability.

Commercial firms have tended to adopt more successful test evaluations because, as a whole, they have an appreciation for "why" testing is conducted vice "how" testing is conducted. In general, the culture of the commercial industry views testing as a method of discovering problems early which results in less expenses later. Corporate support for new product development defuses test results as a threat to program support. Conversely, it is difficult for weapon system programs to compete for approval unless they offer significantly better performance over competing systems while conforming to funding and schedule constraints. In this sense, test results tend to become scorecards that indicate whether a program is ready to proceed or to receive the next increment of funding, an activity that is seemingly intended more for the decision makers above the program. Thus, program managers have incentives to postpone difficult tests while minimizing open communication about test results (GAO, "A More Constructive Test Approach . . ., p. 8).

An initiative to make reliability estimates and reliability achievement demonstration a mandatory part of each phase of the acquisition cycle would alleviate the incentives for program managers to postpone difficult testing. If implemented, the initiative would help ensure the attainment of increasing levels of system reliability as the program matured, by requiring demonstrated levels of reliability before major programmatic approvals and milestones.

5. Comparing and Assessing Required, Estimated, and Achieved Reliability

It is important to have a systematic process in place for collecting and comparing reliability data for several reasons. The Marine Corps must be able to calculate and compare the reliability that is being achieved in the field during post-production with the required and estimated reliability in order to determine contactor compliance, successfully hold contractors to their estimates, and determine if the user reliability requirement is being met.

The basic policy of DoD is to hold contractors responsible for quality of the products through various types of quality assurance programs. This obviously requires a plan and action, which must be based on the quality requirements outlined in the ORD. To do so, it is recommended that a program use the reliability requirements stated in operational requirements, or those resulting from trade-off analysis, as a baseline for reliability assessment to be compared with actual achieved field reliability. However, the difficulty remains in collecting, interpreting, and comparing operational (achieved) reliability with contractual reliability measurements. Aside from the essential collection of achieved field data, original contractor estimates and ORD requirements must be retained for comparison, and sustainment organizations must have the resources to enforce contractual terms.

It is well known that "you can't manage what you don't measure," and in general, survey responses indicate that there is a lack of a systematic process for collecting reliability trend data beyond readiness ratings for Marine Corps ground equipment. Furthermore, what data that does exist is suspect to error and corruption as a result of the current maintenance management automated information systems. There was also a consensus that traditional test and evaluation RAM metrics are not supported by maintenance management data systems. This was voted as the top rated inhibitor to effective reliability management, according to the responses from the first question of the survey. With these factors in mind, it is seemingly impossible to compare contractual reliability and/or test estimates in the form of MTBF with corrupted operational reliability data in the form of MTBM, as attained from the Marine Corps maintenance information systems.

a. Maintaining Reliability Requirements and Reliability Estimates

Documentation of contractor estimates is not typically retained while ORD reliability requirements are often difficult to locate. None of the participating programs were able to identify the level to which the contractors' estimates were demonstrated (during testing phases or sustainment) due to the fact that contractor estimates were not retained. In some cases, the ORD could not be found, meaning the original reliability requirement was not retained. These facts indicate that there is an apparent traceability issue within the program offices of legacy systems.

b. Calculating Achieved Field Reliability

Most of the programs surveyed indicated that achieved field reliability data compiled during the sustainment phases of the respective systems is suspect to error, making the comparison of such data with the contractor estimates and original ORD requirements (when available) questionable.

When attempting to compare reliability requirements, reliability estimates, and achieved reliability, there are numerous data deficiencies that the Marine Corps has been forced to overcome. First, the calculation of MTBF is unfeasible at this time utilizing the traditional maintenance data available from current maintenance management systems. Next, it is arguable whether MTBM is a feasible surrogate for MTBF, due to the inclusion of preventive maintenance actions used in calculating this measurement. Even so, the data used for MTBM calculation is often skewed for various reasons, discussed in following sections. Thus, the logistics and program management communities have been forced to use the "next best measurement," operational availability, to attempt to measure system reliability. The question remains whether operational availability can be used or translated to make a valid comparison with the contractors' original reliability estimates in terms of MTBF, MTBOMF, MTBM, etc.

<u>Mean Time Between Failure</u>. It is important to distinguish why MTBF needs to be calculated for equipment. First, contractor reliability estimates are typically provided in the form of MTBF, as derived from operational requirements. As a result, the contractual reliability, expressed in inherent values and used to define, measure, and evaluate the contractor's program, is also typically in the form of MTBF. In order to successfully hold contractors to their estimates, the Marine Corps must be able to calculate the reliability that is being achieved in the field during post-production. Second, the calculation of this time is also necessary in order to determine whether the mean time between failures is increasing, decreasing, or remaining constant with age. As equipment ages, its MTBF decreases until the cost of keeping that item operational is more than the cost of buying a new item. Estimates of when maintenance costs will exceed acquisition costs are questionable without mean time between failure calculations (Enholm, p. 1). In other words, MTBF data analysis helps to determine or confirm if equipment is in the "wear-out" phase of its life cycle and at the end of its economic

useful life. Next, the determination of MTBF can serve to indicate whether Depot Level Maintenance programs are providing a cost effective benefit by comparing reliability metrics prior to, and after depot level maintenance, allowing decision makers to tradeoff expected readiness for DLM cost avoidance. Lastly, MTBF could be used as an input to determine the optimal provisioning of spare parts, utilizing commercial Readiness Based Sparing (RBS) packages and techniques.

Operational usage data is required to calculate MTBF. However, the current Marine Corps maintenance management data systems are not capable of tracking operational usage. Additionally, there are concerns as to which time unit of measurement is most appropriate for calculating MTBF. While MTBF is traditionally calculated as a time between failure, other units such as mean mileage between failures, mean operations or starts between failures, or mean rounds fired between failures may be better indicators of failure intervals. It may be possible to construct a sophisticated algorithm to determine a mean mileage (or other form of operation) for specific fleet equipment, but the error rate would be relatively high due to the often inaccurate and unusable meter readings of USMC field equipment.

For systematic failure or maintenance degradation, there is also a requirement that the age of the system be established. Particularly, this is important when attempting to establish the age when a system starts spending more time in a non-mission capable status as it gets older and maintenance requirements start adversely affecting operations. However, there is not a central repository or data source where the Marine Corps collects information establishing the economic useful life of serialized items. While the program management offices sometimes keep a logbook detailing when specific serial numbers were fielded, the information is not always readily available (Enholm, p. 2).

<u>MTBF vs. MTBM vs. A_o</u>. The Marine Corps is forced to substitute MTBF with either MTBM or A_o due to lack of operational usage data needed to calculate MTBF. The feasibility of this substitution is questionable due to the inclusion of both preventive and corrective maintenance actions in the calculation of MTBM. Additionally, even the calculation of MTBM is often suspect to error due to various

factors contributing to a lack of quality maintenance data, and as indicated in the previous chapter as well as Appendix C, MTBM can only intermittently be calculated for certain equipment.

As a result, "R-rating" or readiness rating is computed per Marine Corps Bulletin (MCBul) 3000 as a substitute to both MTBF and MTBM, offering what is perhaps, the most feasible estimate of a measurement for reliability achievement. R-rating basically provides a snapshot of operational availability (A_o), as discussed in Chapter II. Recalling that,

$$A_o = \frac{uptime}{uptime + dowtime} = \frac{MTBM}{MTBM + MDT} = \frac{\overbrace{OT + ST}^{UPTIME}}{\underbrace{OT + ST}_{UPTIME} + \underbrace{ALDT + CMT + PMT}_{DOWNTIME}}$$

it is important to note that the Administrative Logistics Delay Time (ALDT), Corrective Maintenance Time (CMT), and Preventive Maintenance Time (PMT) are included in the calculation of downtime when computing operational availability. This is largely due to the fact that such variables are difficult to extract and distinguish amongst one another as a result of weaknesses with the current maintenance management data systems and tracking procedures. Operational availability can also be improved by maintaining a large stockage of frequently used spare parts. While availability is improved, the logistics burden is significant.

<u>Factors Contributing to Skewed Data</u>. As indicated by a majority of the survey respondents, there is an obvious lack of quality historical maintenance data, attributable to numerous causes, some of which are highlighted in this section.

When attempting to compare the required, estimated, and achieved reliability of weapon systems with the limited data available, it is important to take into account that the respective readiness rates most often include all inventory within the Marine Corps. This may actually skew the snapshot of overall achieved reliability for particular systems. In other words, reliability based on readiness rates may appear to be higher than what is really being achieved due to the equipment in stores and on Maritime Pre-positioning Force (MPF) ships positively affecting the overall readiness rates for a specific system. The stores and MPF equipment have an extremely low usage rate and

are well maintained. An additional data set that excludes stores and MPF equipment would be required to test this hypothesis.

Depot Level Maintenance Programs are conducted on systems that have shown trends of decreasing readiness corresponding with increased age, that have exceeded or approached their expected useful lives, or that are will be required to be operational for extended periods without a replacement system. DLM programs are specifically designed to have a significant improvement on the reliability, availability, and maintainability of the systems. As a result, there is likely an impact on the achieved reliability data that is collected for comparison to required and estimated reliability. In order to accurately account for the effects of improved reliability, the data collected on the systems must be separated into those that have undergone DLM and those that have not.

Selective interchange, replacement of major system components, and maintenance actions, in general, affect the overall inherent reliability that a system was "designed to." As such actions change the reliability and availability of an end item, it becomes virtually impossible to compare what the system was supposed to achieve, according to contractor/Government estimates, and what it is actually achieving in the field. Additionally, "operator- and maintainer-induced failures" result in a reliability achievement that is less than the inherent reliability of the system, but these incidents are also largely unknown.

Lastly, Equipment Repair Orders (EROs), used to initiate maintenance activities, often include multiple failures on a single document, creating inconsistencies in the calculation of MTBM. Also, the source of the data maintenance and supply data is from two disparate systems, MIMMS and ATLASS, respectively.

c. "Reliability Gap"

The absence of retained data within the acquisition and logistics communities, combined with the lack of survey participation, led to an inconclusive hypothesis whether a "reliability gap" actually exists between the original reliability requirements, contractor/Government estimates, and achieved field reliability. However, the survey respondents' acknowledgements to an absence and inaccuracy of the requested

reliability data supports the concept that there is an issue with respect to calculating, retaining, comparing, and assessing reliability achievement and trends of mature systems as well as original contractor reliability estimates and ORD requirements. In this case, "no data, is data."

C. LESSONS LEARNED

Program Offices of Marine Corps legacy weapon systems, procured decades ago, had not always taken advantage of effective reliability management opportunities. The proper level of managerial attention, in the realm of reliability, was not given to the systems primarily due to the lack of focus on RAM metrics and LCC concerns. However, it is promising to see the increased focus and attention given to reliability performance of the AAAV program, likely representative of future programs to be developed within Marine Corps acquisitions.

Today, it is well known that there are many opportunities to address reliability within weapon systems acquisitions - from requirements generation and contracting to the conceptualization, design, and development utilizing the systems engineering process to demonstration and incremental testing throughout development to the operational monitoring and comparing of achieved reliability with the estimated reliability to ensure attainment of reliability as planned. However, procedural, managerial, and incentive pressures still force program offices to sacrifice reliability for the achievement of other goals such as time, money, and performance.

The concept of reliability is often utilized without precise definition, while the terminology is non-standard throughout the logistics community and tends to depend on the system being developed. However, while creating DoD requirements documentation, contract specifications, and test documentation, it is very important that all main concepts are addressed in an unambiguous way so that all parties involved (to include the user, combat developer, materiel developer, PM, contractor, and tester) understand the terms. A common problem emerges in the translation of operational reliability requirements into contractual reliability requirements, as they typically are expressed in different terms. Operational reliability parameters, as described by the user and Combat Developer, are often in terms of operational availability or mission duration needs. The Materiel Developer takes these parameters and allocates them to technical reliabilities of the

system in the terms of MTBF, traditionally the common parameter of reliability used for contractual purposes. Then, the focus for the PM is to ensure the contractual reliability of the system, as measured in controlled test conditions, supports the dynamic and unpredictable environment in which operational availability is measured.

The essential documentation and collection of achieved field reliability data, original contractor estimates, and reliability requirements are not typically retained or are difficult to locate, making comparison of such measurements impossible. In fact, none of the participating programs were able to identify the level to which the contractors' estimates were achieved during operational testing, developmental testing, and the sustainment phase due to the fact that contractor estimates were not retained by any of the programs examined. In some cases, the ORD could not be found, meaning the Government's original reliability requirement was not retained either. Additionally, many of the survey participants noted that developmental test data was difficult to come by while operational test data was somewhat more readily available due to the role of independent Government testing agencies, such as MCOTEA. Lastly, a difficulty remains in collecting and computing accurate operational reliability data as most programs indicated that achieved field reliability data compiled during sustainment of the respective systems is suspect, making the comparison of such data with the original ORD requirement and contractor estimate (when available) questionable.

Prior to research and data collection attempts, PMOs seemed to be the likely place to find original documents and data such as ORDs, reliability requirements, contracts, contractor reliability estimates, and achieved reliability data. Research ascertained that there was a retention, traceability, and computation problems with original documents and reliability data.

As demonstrated in the MTBF/Maintenance Study (Appendix C) conducted at MARCORMATCOM, it is possible to calculate a sample mean or median time between failure (and maintenance combined) for some Marine Corps equipment using advanced methodologies, but the accuracy of the calculations is suspect due to weaknesses in maintenance management data systems. Likely due to the difficulty, inability, and errors

involved with such attempts, there is not a requirement to track the MTBM or MTBF of systems during their operational life cycles.

The maintenance data available using the Marine Corps' current maintenance management data systems (MIMMS/ATLASS II/SASSY) does not provide the adequate information necessary to calculate MTBF and is suspect to corruption and error. Specifically, the Marine Corps is unable to calculate failure rates because there is not a way to track the operational usage of end-items. Perhaps a feasible solution will arise with the implementation of the Global Combat Support System-Marine Corps (GCSS-MC). The GCSS-MC system will replace our current legacy maintenance systems and could possibly contain serialized records for primary end items, permitting the tracking of operational usage, which is necessary in the calculation of MTBF. Navy and Marine Corps supply/maintenance procedures used to track flight hours on naval aircraft may offer possible solutions to tracing operational usage of USMC ground equipment.

Managing reliability does not end with OT&E and fielding of the system, and instead, reliability must be continually monitored and assessed for potential improvements and efficiencies in support of meeting Marine Corps life cycle cost and readiness objectives. In fact, once a system is fielded, reliability assessment should become a permanent part of sustainment activities conducted by Program Management Offices as well as other Life Cycle Management organizations. To be successful, reliability growth must continue during the customer-use phase by coordinating feedback from the warfighters to the suppliers and by supporting necessary corrective actions.

D. CHAPTER SUMMARY

This chapter analyzed common PM issues and challenges involved with managing the reliability performance of Marine Corps ground equipment. The analysis was based on program data and results from a reliability management survey administered to various personnel associated with the acquisition process. The chapter was formatted around the five major reliability management issues, derived for the purpose of this research. The final chapter will provide selected conclusions focused on the research questions while relaying some recommendations on how to best approach reliability issues from a management standpoint.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

Research conducted in support of this thesis evaluated system reliability management in the acquisition process as it applied to selected principle end items within the Marine Corps ground equipment inventory. Common inhibitors and enablers of effective reliability management, why they occur, lessons learned, and potential methods for mitigating the inherent risks are collectively summarized and analyzed as derived from surveys, interviews, and existing maintenance data. The research ascertains a variety of technical, programmatic, managerial, incentive, and procedural issues that the Marine Corps encounters concerning system reliability requirements and achievement. The overall intent of this research is to provide Program Management Offices, acquisition organizations, and strategic planners insight into the collective experiences and perspectives of acquisition workforce professionals who are familiar with issues relating to reliability management. The results of the thesis serve to provide insight into the improved sustainability of future systems while encouraging the development of a mechanism that enables the traceability of contractual reliability performance requirements to operational reliability requirements.

In this final chapter, as a result of feedback and analysis of survey responses, selected conclusions are presented that focus on and answer the research questions, while potential recommendations are identified on how to best approach reliability issues from a managerial standpoint. The thesis concludes with recommended areas for further research.

B. CONCLUSIONS AND RECOMMENDATIONS

Subtle flaws in design affect system reliability and can have multi-million dollar effects as LCC continue to escalate throughout the life of the system. In the extreme, such subtle design flaws can become potentially catastrophic. The DoD needs to focus on the goal of providing a system that maximizes its operational availability within the targeted life-cycle cost of the program, and one of the primary methods of doing so is to practice effective reliability management.

1. Documentation and Data Retention Required for Reliability Assessment

Conclusion: Prior to research and data collection attempts, PMOs appeared to be the likely place to find original documents and data such as ORDs, reliability requirements, contracts, contractor reliability estimates, and achieved reliability data. The failure to retain such documentation and the absence of reliability data within the acquisition and logistics communities, combined with the lack of survey participation, led to an inconclusive hypothesis whether a "reliability gap" actually exists between the original reliability requirements, contractor/Government estimates, and achieved field reliability.

However, research ascertained that there was a retention and traceability issue with reliability requirements, reliability estimates, and original documents. The survey responses, citing an absence and inaccuracy of the requested reliability data, indicate that there is an issue with respect to calculating, comparing, and assessing reliability achievement and trends of mature systems as well as retaining the original contractor reliability estimates and ORD requirements. In this case, the author believes that the lack of this data was central to the intent of the thesis.

Recommendation: In order to hold contractors to their original reliability estimates, it is recommended that a baseline for reliability assessment, such as the reliability requirements stated in operational requirements and performance specifications, be maintained to be compared with achieved field reliability. The well-meaning, but ineffectual philosophy often applied to reliability – "we will do the best we can" must be replaced with a contractual obligation in the form of measurable quantitative system reliability requirements and appropriate databases of fielded system reliability performance.

2. Reliability Management Control Systems

Conclusion: The Marine Corps acquisition community lacks adequate management control systems to ensure reliability performance meets predetermined requirements and contractor pre-fielding estimates.

Recommendation: Mandate that required, predicted, and demonstrated reliability be made a mandatory component of each phase of the acquisition cycle; that is,

require that realistic reliability predictions and demonstrations of achievement be incorporated into each Milestone Decision to be compared with the original requirements. This would allow the MDA to address reliability performance progress and plans for achieving the reliability thresholds of a system at every major review of a program. To do so, thresholds, or intermediate benchmarks representing minimum reliability achievement levels, should be established at various points of the program as a risk management technique. A breach of such a threshold could serve to indicate that the program is not on track in terms of reliability requirements, and intervention may be required to correct the discrepancy, if necessary.

The Acquisition Program Baseline should continue to serve as a "contract" of sorts between the PM and the MDA. Reliability related parameters such as MTBF, A_o, and MTBM must exist for each program either in the Performance or Supportability sections of the APB. The acquisition program baseline status of each program must be reviewed at regular intervals and at major reviews.

Additionally, when a program reaches a major milestone or experiences a significant change in its program parameters, the outcome is documented in an ADM. The Acquisition Decision Memorandum typically includes additional directives and statements with which the PM must comply, and thus, it needs to be approached as an opportunity for the MDA to encourage the achievement or improvement of reliability levels, while placing entrance criteria, constraints, or follow-on actions related to reliability on the programs.

3. Reliability Policy, Regulations, and Guidance

Conclusion: Predominantly as a result of acquisition reform, acquisition workforce professionals lack adequate guidance and requirements in the form of policy, publications, and directives, to guide them in the conduct of reliability activities. Additionally, the amount of mandatory guidance is minimal and has further decreased in recent years due to acquisition reform initiatives. Consequently, the acquisition community often utilizes an abundance of cancelled MIL-STDs and MIL-HDBKs or vague discretionary guidance to guide them in reliability related decision-making.

<u>Recommendation</u>: DoD should couple with commercial industry prime contractors to develop a comprehensive set of reliability management standards, which consider life cycle cost and sustainment consequences of early life cycle decisions.

4. Reliability Roles

<u>Conclusion</u>: Throughout the program offices of the legacy systems examined, there was no consistent managerial approach to reliability responsibilities, and while this may allow for flexibility, programs sometimes seemed to lack a clear understanding of who is responsible for reliability activities within a program.

<u>Recommendation</u>: There should be a formally chartered Reliability IPT, responsible for ensuring effective communication between the program, us er, contractor, RAM community, engineers, testers, and logisticians. The IPT must be involved from concept exploration, affecting requirements establishment, analysis, and influence over the design factors.

5. Reliability Requirements Generation

<u>Conclusion</u>: There does not seem to be a consistent process for establishing operational reliability requirements performance measures during attempts to "link reliability performance to mission or supportability measures", as required by DoD 5000.2-R. In other words, the terms in which the reliability requirement was identified varied from program to program. Additionally, reliability has typically not been a Key Performance Parameter in the Operational Requirements Document for Marine Corps legacy systems, and, it gets pushed aside due to other requirements precedence to include cost, schedule, and performance objectives. Lastly, amongst the legacy systems examined, reliability was not used as a source selection factor.

<u>Recommendation</u>: It is recommended that standards be established for defining reliability measures in the ORD. Reliability, along with cost, maintainability, and performance, should be considered equally in the requirements generation process, a stage at which the Materiel Developer and Combat Developer should be jointly defining realistic, achievable reliability requirements. To attain desired reliability performance thresholds and goals, it is recommended that robust reliability requirements be clearly defined and communicated as KPPs in the ORD, in clear operational terms by the Combat Developer. Likewise, reliability should appropriately be considered as a source

selection factor during solicitation. The reliability objectives must then be translated into quantifiable and verifiable contractual terms, traceable back to the system performance and the operational requirements. The Materiel Developer must adequately translate the system operational terms into viable contractual terms, understood by all parties involved to include the user, the program office, and the contractor so that compliance can be adequately monitored and enforced. Ultimately, it is recommended that Performance Specifications include an inherent reliability goal, and when such goals are not achieved, it should be considered a latent defect.

6. Reliability Program Plan

Conclusion: For the most part, Marine Corps legacy programs did not have structured reliability management processes in place, nor did they have corresponding overarching documents that define the activities, schedules, resources, and reliability achievement strategies needed to provide managerial insight into the programs' reliability objectives. Consequently, Program Management Offices have not traditionally taken advantage of the numerous test and design tools available to them and contractors that help to ensure reliability is "designed in" early in the program by determining potential failures and the causes of such failures. "Designing-in" reliability upfront reduces risk and is less costly than finding design discrepancies during later stages of testing, evaluation, and operational use.

Recommendation: In order to provide visibility into the management, functions, and responsibilities of those parties responsible (Government and contractor) for the reliability activities within a program, require all PMs to develop a Reliability Program Plan. This should be a mandatory document for all Milestone Decision Reviews, providing definitive documentation on all reliability activities, functions, processes, test strategies, measurements/metrics, data collection, resources and timelines required to ensure system reliability maturation.

7. Impact of Inaccurate Reliability Estimates: Tying Contractors to their Estimates

Conclusion: Foremost, systems that fail to meet reliability goals do not perform as expected, and the failure to meet such performance expectations proves to be costly in both operational and financial terms. Logistical support decisions are based upon

expected system reliability as determined early during development. Consequently, inaccurate reliability estimates significantly increase life cycle costs while adversely affecting the quality of logistical support available throughout the systems' life cycles. In other words, when achieved field reliability is significantly less than what was anticipated, numerous deficiencies occur in the attempt to support maintenance requirements to include inadequate initial provisioning of spare parts, insufficient number and level of training for mechanics, deficient facilities and test equipment, and inadequate funding plans for future budgets.

Recommendation: Contractors must be tied to LCC through their reliability estimates. Attempts must be made to use reliability incentives and warranties, and the Marine Corps must establish a mechanism that allows for the traceability of contractual reliability performance requirements to operational performance requirements. Likewise, the DoD must adopt the null hypothesis that the reliability is not what the contractor claims, but rather, what the contractor proves. To do so, the Government must validate the contractor's estimates. Once the contractor submits their RAM estimate, it becomes the Government's estimate only if they accept it. Therefore, it's up to DoD to become involved in this process and to conduct independent testing as necessary to verify such estimates.

Another alternative is to utilize Contractor Logistical Support (CLS) for a specified interim period to ensure contractors are tied to accurate reliability estimates prior to transitioning the logistical support role to the military. After an accurate operational reliability measurement is determined through field operations, the Marine Corps can enforce contract provisions and optimally plan for and implement logistics support based upon actual achieved reliability. Traditionally, CLS has been utilized in cases where the military was not yet in a position to provide logistical support for a system that needed to be fielded rapidly. The author proposes the intentional use of planned CLS for a predetermined period, perhaps two to three years, to ensure that the system reliability is what the contractor had claimed, to be able to enforce contract provisions, and to plan for effective system supportability to achieve desired system performance.

8. Reliability Assessment Metrics

Conclusion: Traditional T&E RAM metrics are not supported by current Marine Corps maintenance data sources, and thus, it is difficult to make a valid comparison between reliability requirements, as stated in the ORD; contractor RAM estimates; and data from actual achieved reliability of fielded systems. Specifically, USMC maintenance management systems do not track the necessary operational usage data required to accurately compute failure rate (in the form of MTBF), and instead, the current systems enable the computation of maintenance rate (in the form of MTBM), which includes both preventive and corrective maintenance as well as other skewing factors. The accuracy of the MTBM calculation is suspect to corruption and error due to weaknesses in maintenance management data systems and inefficiencies in the administrative maintenance processes. As a result, it is extremely difficult to accurately compare contractual reliability and/or test estimates in the form of MTBF with corrupted operational reliability data in the form of MTBM, as attained from the Marine Corps maintenance information systems.

Additionally, the concept of reliability is often utilized without precise definition, and the terminology is non-standard throughout the logistics community, tending to depend on the system being developed. However, while creating DoD requirements documentation, contract specifications, and test documentation, it is very important that all performance terms, including supportability performance terms, are addressed in an unambiguous way so that all parties involved (to include the user, combat developer, materiel developer, PM, contractor, and tester) understand them. A common problem emerges in the translation of operational reliability requirements into contractual reliability requirements, as they typically are expressed in different terms. The focus for the PM is to ensure the contractual inherent reliability of the system, as measured in controlled test conditions, supports the dynamic and unpredictable environment in which operational availability is measured.

Recommendation: Foremost, the operational and contractual reliability requirements must be measurable, verifiable, and most importantly, they must be comparable in an objective and quantifiable form that are contractually enforceable and that contractors and the Government can easily agree upon.

The author recommends that a feasible solution to track operational usage, enabling the calculation of MTBF, be included with the implementation of the Global Combat Support System-Marine Corps (GCSS-MC). The GCSS-MC system will replace current USMC legacy maintenance systems, and the author suggests that the replacement system contains serialized records for primary end items, permitting the tracking of operational usage, which is necessary in the calculation of MTBF. Additionally, weapon systems should be designed that, through modern technology, are able to self-monitor operational usage in terms of hours, starts, rounds fired, miles, or other applicable metrics. Another alternative is to consider Navy and Marine Corps supply/maintenance procedures used to track flight hours on naval aircraft as ways to offer possible solutions to tracing operational usage of USMC ground equipment.

9. Cost Metrics

Conclusion: Under current methods of utilizing unit production cost as a metric that determines the success of a program for the MDA, reliability and life cycle cost issues are often ignored to produce a lower unit cost. Likewise, while the acquisition workforce recognizes the significance of reliability, it typically gets pushed aside in the short-term crisis management environment of a constrained resources acquisition community where PMs are evaluated on procurement cost, schedule, and performance.

Recommendation: Mandate the use of life cycle cost, within performance parameters, as the basis for all design trade-offs. However, DoD must develop a performance measure and incentive structure that recognizes life cycle cost equal to, or higher than the current acquisition cost, schedule, and performance metrics.

Additionally, there needs to be a greater awareness by program management offices of the availability and capabilities of commercial LCC models. Such models should be utilized to assess the reliability, LCC, and logistics supportability impacts of various equipment configurations and other design and supportability issues. The commercial models should be used to provide design and support tradeoff, with sensitivity and comparative analysis, to ensure the program meets adequate reliability goals within, or below respective LCC budgets.

10. Inherent vs. Achieved Reliability: Consideration of Reliability Degradation

<u>Conclusion</u>: There will likely be a difference between inherent (or potential) reliability and achieved reliability as demonstrated in the field. The operation and maintenance of equipment in the field often induces these effects by overstressing systems beyond predicted levels as a result of neglect, unfamiliarity, carelessness, and mission constraints. Additionally, the true achieved reliability can be obscured by scheduled and unscheduled maintenance actions and the corresponding administrative actions, conducted by inadequately trained personnel, mandated by incorrect diagnosis, or simply poorly managed.

<u>Recommendation</u>: While a major effort is made in operations to reduce the effects of reliability degradation caused by maintenance, the designer should consider the risks of field maintenance and minimize the characteristics of the design that are susceptible to operationally induced reliability deterioration. Every effort should be made by both the Materiel Developer and the contractor (through contractual language) to minimize potential human error. This may be accomplished with technologies such as bit/bite, diagnostics, prognostics, and autonomics. Equally important, reliability predictions should be made on realistic operational projections for degradation.

Contractors should account for all elements contributing to the combined failure rate and provide the Government with a confidence interval for a predetermined readiness performance in the form of operational availability. Such concepts remain the premise behind the idea of Performance Based Logistics, which is a strategic approach to provide long-term measurable product sustainment to the warfighter. A realistic reliability requirement must account for all application environments and the time proportions expected in each phase or product life cycle of a system such as storage, transportation, installation, standby, and operation, and an apportionment of the requirement across the life cycle phases must account for deterioration in each phase.

11. Continuous Reliability Assessment

<u>Conclusion</u>: Managing reliability cannot end with OT&E and fielding of the system. Typically, legacy weapons systems did not implement formal reliability growth plans to ensure established reliability maturity levels were achieved during system

sustainment periods. Performance thresholds linked to system sustainability may or may not have been met, and unfortunately, the USMC does not know which is the case.

Recommendation: Reliability must be continually monitored and assessed for potential improvements and efficiencies in support of meeting Marine Corps life cycle cost and readiness objectives. Once a system is fielded, formal reliability assessment should become a permanent part of sustainment activities conducted by Program Management Offices under the realm of the life cycle Weapon System Manager with assistance from the Logistics Management Specialist. To be successful, reliability growth must continue during the customer-use phase by coordinating feedback from the warfighters to the suppliers and by supporting necessary corrective actions. The data required for this effort must be collected in a method that is transparent to the operators and maintainers.

C. RECOMMENDATIONS FOR FURTHER STUDY

The following topics could have significant influence in the area of reliability management but fall beyond the scope of the present research, and thus, they are recommended topics for additional research:

- Conduct a quantitative assessment to determine the level of confidence that can be realized when substituting MTBF with MTBM or A_o calculations. Such a study could help to more accurately determine if these measurements are feasible surrogates for one another.
- Conduct a similar study that encompasses a larger spectrum of programs, to include various ACAT levels as well as systems in various acquisition phases.
- Conduct a similar survey conducted from the perspective of the contractor, who is expected to provide systems capable of achieving a predetermined required level of reliability.
- Examine the feasibility of utilizing Contractor Logistical Support for a specified interim period to ensure contractors are tied to accurate reliability estimates prior to passing the logistical support role onto the military once actual reliability is determined through field operations.
- Analyze the applicability and feasibility of utilizing reliability warranties and incentives in contracts to achieve more accurate reliability estimates from contractors to which they can be help accountable.
- Using a commonly identified commercial life cycle cost model, conduct a sensitivity analysis of how changes in reliability affect operations and support costs.

- Conduct a study to determine the political and cultural barriers to increasing RDT&E investment, a funding investment that although increases procurement costs, may lead to more accurate reliability estimates and ultimately decrease LCC.

D. THESIS SUMMARY

Weapon system reliability demands constant managerial attention and implementation of effective management and technical strategies that balance cost, schedule, and performance with reliability during systems' entire life cycles – from conceptualization and development to fielding and operational support through disposal. It is imperative to have early identification of upfront cost-effective opportunities for achieving the required reliability while obtaining and utilizing accurate reliability estimates for logistical support decisions. Mitigation of associated reliability risks during design, manufacturing, development, testing, and post-production operations must be accomplished to reduce the potential for unexpected life cycle cost inflation and decreased operational availability. Likewise, programs that have carefully planned and executed reliability management techniques will be more combat effective, in the way of decreased life cycle costs and increased operational availability, during the useful life of the systems.

The bottom line remains that increased reliability of weapon systems contributes directly to greater combat effectiveness. To fight and win wars, Marines must be equipped with systems that are reliable. Progress must continue to be made to ensure that inhibitors to effectively provide such lethal systems to the fleet are recognized and mitigated.

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APPENDIX A. ACQUISITION RELATED ACRONYMS

ADM	Acquisition Decision Memorandum
ACAT	Acquisition Category
A_a	Achieved Availability
A_i	Inherent Availability
ALDT	Administrative and Logistics Delay Time
A_o	Operational Availability
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
ASN, RDA	Assistant Secretary of the Navy; Research, Development, and Acquisition
CAE	Component Acquisition Executive
CAIV	Cost as an Independent Variable
CE	Concept Exploration
CMC	Commandant of the Marine Corps
CMT	Corrective Maintenance Time
DAE	Defense Acquisition Executive
DAU	Defense Acquisition University
DFAR	Defense Federal Acquisition Regulation
DLM	Depot Level Maintenance
DoD	Department of Defense
DoDD	Department of Defense Directive
DPG	Defense Planning Guidance
DSMC	Defense Systems Management College
DT&E	Developmental Test and Evaluation
DUSD	Deputy Under Secretary of Defense
ESS	Environmental Stress Screening
FAR	Federal Acquisition Regulation
FMECA	Failure Modes, Effects and Criticality Analysis
FRACAS	Failure Reporting, Analysis, and Corrective Action
GAO	General Accounting Office
ILS	Integrated Logistic Support
IOT&E	Initial Operational Test and Evaluation
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IROAN	Inspect and Repair Only As Necessary

KPP	Key Performance Parameter
LCC	Life Cycle Cost
LRIP	Low Rate Initial Production
LS	Logistics Supportability
LT&E	Logistics Test and Evaluation
M&S	Modeling and Simulation
MARCORSYSCOM	Marine Corps Systems Command
MARCORLOGBASE	Marine Corps Logistics Base
MATCOM	Materiel Command
MCCDC	Marine Corps Combat Development Command
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MIL-HDBK	Military Handbook
MILSPEC	Military Specification
MLDT	Mean Logistics Delay Time
MNS	Mission Need Statement
MOE	Measures of Effectiveness
MS	Milestone
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTTR	Mean Time to Repair
NAE	Navy Acquisition Executive
NMS	National Military Strategy
NSS	National Security Strategy
O&M	Operations and Maintenance
O&S	Operations and Support
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OT	Operating Time
OT&E	Operational Test and Evaluation
PEO	Program Executive Officer
PM	Program Manager
PMO	Program Management Office
PMT	Preventive Maintenance Time
PM/WSM	Program Manager/Weapon System Manager
POM	Program Objectives Memorandum
RAM	Reliability, Availability, and Maintainability
R&D	Research and Development
RDT&E	Research, Development, Test, & Evaluation

RFP	Request for Proposal
RQT	Reliability Qualification Test
SA	Supportability Analysis
SAE	Senior Acquisition Executive
SAMP	Single Acquisition Management Plan
SCM	Supply Chain Management
SECDEF	Secretary of Defense
SEP	Systems Engineering Process
SLEP	Service Life Extension Program
ST	Standby Time
TAAF	Test, Analyze, and Fix
TEMP	Test and Evaluation Master Plan
TOC	Total Ownership Cost
USD (AT&L)	Under Secretary of Defense, Acquisition, Technology, and Logistics
USMC	United States Marine Corps
WBS	Work Breakdown Structure
WIPT	Working-Level Integrated Product Team

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APPENDIX B. PROGRAM MANAGEMENT RELIABILITY SURVEY

Naval Postgraduate School

Monterey, California

Reliability Survey

Instructions:

Please answer the following questions NLT 16 October 02. Your time and effort is greatly appreciated and will hopefully assist in identifying common potential inhibitors of reliability management. ***Results from this survey will be presented in aggregate form, not program specific.***

Please answer all questions. If data or documentation is not available, does not exist, or has not been computed, please specify.

This survey is being conducted to support research as part of a Naval Postgraduate School thesis on reliability management challenges within the Marine Corps acquisition process. The results of the thesis are intended to directly benefit Program Managers by identifying common inhibitors to reliability management, why they occur, lessons learned, and suggestions for reducing the inherent risks. The focus of the research will be a comparison of systems ' reliability requirements and predicted reliability with actual achieved reliability of fielded systems.

The research is limited to a cross-section of mature critical/pacing items included in the Quarterly Readiness Reports to Congress (M1A1 Tank, Amphibious Assault Family of Vehicles, 5 Ton Truck Family of Vehicles, HMMWV Family of Vehicles, Light Armored Family of Vehicles, LVS Family of Vehicles, and the M198 Howitzer). The analysis is limited to an assessment of reliability management and process issues and does not specifically address commodity or technology driven reliability problems.

GENERAL BACKGROUND QUESTIONS

1. Product Group:

2. Program Management Office:

3. Billet/Position (PGD, PM, Deputy PM, Operations Manager, LMS) of Respondent:

4. Program/Weapon System Name (specify variant of the system if applicable):

- M1A1
- LAV
- M198
- D7B, Tractor, Medium
- AAV
- M240G, 7.62mm Machine Gun
- HMMWV
- 5-Ton
- MK-48, LVS Power Unit
- AN/PRC-119
- Other (Please Specify)

5. Current Life Cycle Phase:

- Phase III of old 5000 series: How long has the system been in the field post-IOC (in years)? # of years
- Milestone C of new 5000 series: How long has the system been in the field since post-Full Rate Production and Deployment (in years)? # of years

6. What was the intended life cycle of the weapon system?

MANAGING RELIABILITY

7. Rank order what you consider to be the TOP FIVE reliability management problems (1 being the most severe problem):

- [ ] Traditional test and evaluation RAM metrics are not supported by our maintenance data sources (unable to make a valid comparison between RAM requirements and estimates with actual achieved field data)
- [ ] Reliability is not a Key Performance Parameter in the ORD
- [ ] Missing or poorly written ORD reliability requirements
- [ ] Misinterpretation of reliability related performance specifications
- [ ] Contractor not designing for reliability sufficiently above the requirement
- [ ] Acquisition streamlining and/or government downsizing
- [ ] Contractor not using best commercial practices
- [ ] Poor reliability planning and growth planning (test too late)
- [ ] Inadequate or vague policies and guidance (need updating)
- [ ] Insufficient reliability testing to verify requirements
- [ ] Too much pressure to field system cheaper (Cost goals outweigh reliability)
- [ ] Too much pressure to field system more rapidly (Schedule goals outweigh reliability)
- [ ] Unrealistic reliability requirements with inadequate rationale
- [ ] Need more qualified personnel in reliability management in PM office
- [ ] Not consistently improving reliability after fielding
- [ ] Other:

Additional Comments:

8. Who within your organization is primarily responsible for reliability activities for this particular program? (Check only one)

- Program Manager (PM)
- Logistics Management Specialist (LMS)
- Project Team Leader (TL)
- Systems Engineering Team Leader
- Logistics/Supportability Team Leader
- Test Team Leader
- Reliability IPT (If so, is it a formally chartered IPT?) Yes No
- Prime Contractor
- No one specifically
- Other

9. How is the system reliability program and corresponding management approach formally documented within your program? (Please check only the primary overriding document)

- Reliability Program Plan
- Contract SOW
- TEMP (Test and Evaluation Master Plan)
- SAMP (Single Acquisition Management Plan)
- No formal reliability management plan
- Other (Please Explain)

10. Which activities did/does your program implement to recognize and/or evaluate potential failures and causes? (Please check ALL that apply)

- [ ] Operation Testing
- [ ] Developmental Testing
- [ ] Environmental Stress Screening (ESS)
- [ ] Reliability Modeling
- [ ] Reliability Qualification Test (RQT)
- [ ] Process Failure Modes and Effects Analysis (PFMEA)
- [ ] Weibull Analysis
- [ ] Physics of Failure (POF)

☐ Reliability Allocation
☐ Fault Tree Analysis
☐ Probabilistic Failure Assessment
☐ Failure Modes, Effects and Criticality Analysis (FMECA) or FMEA
☐ Reliability Development/Growth Test (RD/GT)
☐ Failure Reporting, Analysis, and Corrective Action (FRACAS)
☐ Parts Control Program
☐ Other
☐ Do not know

11. Are you aware of any specific DOD or Marine Corps policy/regulations regarding weapon system reliability management?

○ Yes (If yes, which do you use to help you manage reliability?)
○ No

Do you feel that existing policy and regulations on reliability provide adequate guidance? Please explain.

ADDRESSING RELIABILITY IN THE REQUIREMENTS GENERATION PROCESS

12. What was the documented reliability/availability requirement? In what terms was it measured (i.e. MTBF, MTBM, A_o, MTBSA, MTBOMF, MTBEFF, MTBOMA, MTBMAF, etc)?

13. Was a reliability requirement identified as a Key Performance Parameter (KPP) in the Operational Requirements Document (ORD)? If so, was the requirement in an objective and quantifiable form that contractors and the government could easily agree upon? Please explain.

14. Was the PMO, as the Material Developer, able to influence incorporation of realistic reliability requirements as part of the ORD process? ○ Yes ○ No ○ Not Sure

Additional Comments:

CONTRACTING FOR RELIABILITY

15. Was reliability included as a factor in the source selection process?

○ Yes (Was it a significant discriminator? ○ Yes ○ No)
○ No

Additional Comments:

16. How are ORD reliability requirements for your program translated into actual contractual reliability requirements?

○ ORD paragraphs relative to reliability are restated in SOW/Spec (i.e. contract requirement is equal to ORD requirement)
○ Additional levels of reliability are applied to the contract (Please briefly describe the process)

- Comprehensive reliability requirements are not adequately stated in the contract
- Other (Explain)

17. Are there incentives employed in the contract that are specifically tied to achieving system reliability performance requirements?

- Yes (Explain)
- No

18. If yes, did these incentives achieve their desired effect?

- Yes
- No
- Too early to tell

Additional Comments:

DEVELOPMENTAL AND OPERATIONAL TESTING

19. Did the user, tester, contractor and PM office all agree upon the method (model) to be used to determine reliability performance during testing?

- Yes (If yes, Where is this documented? TEMP?)
- No
- Not Certain

Additional Comments:

20. Did your program have specific IOTE entrance criteria relative to reliability?

- Yes (please provide details)
- No

Additional Comments:

21. Was the amount of time and funding allotted for reliability testing during DT sufficient for your program'

- Yes
- No

Additional Comments:

22. Did the system experience any major reliability test failures?

- Yes
- No

Additional Comments:

RELIABILITY REQUIREMENTS VS. CONTRACTOR ESTIMATES VS. ACHIEVED RELIABILITY

23. To what level was your system 's ORD reliability requirement demonstrated? (state in terms of % of ORD requirements met by selecting one from each column)

During DT:	During OT:	During Sustainment:
100 %	100 %	100 %
>90 %	>90 %	>90 %
>80 %	>80 %	>80 %
>70 %	>70 %	>70 %

>60 %	>60 %	>60 %
>50%	>50%	>50%
20-50%	20-50%	20-50%
<20%	<20%	<20%
Do NOT know	Do NOT know	Do NOT know
Not Applicable	Not Applicable	Not Applicable

24. To what level was the contractor's reliability estimate demonstrated? (state in terms of % of estimate met by selecting one from each column)

During DT:	During OT:	During Sustainment:
100 %	100 %	100 %
>90 %	>90 %	>90 %
>80 %	>80 %	>80 %
>70 %	>70 %	>70 %
>60 %	>60 %	>60 %
>50%	>50%	>50%
20-50%	20-50%	20-50%
<20%	<20%	<20%
Do NOT know	Do NOT know	Do NOT know
Not Applicable	Not Applicable	Not Applicable

25. Was the initial contractor reliability estimate documented?

Yes No (If yes, on what document?)

Is such documentation retained?

Yes No (If yes, where (physically) and by whom?)

26. What was the initial (prime) contractor reliability estimate for the system?

In what terms was it measured (i.e. MTBF, MTBM, A_o)?

27. Has actual achieved reliability of the fielded system been collected/computed? Yes No

If so, in what form (i.e., MTBF, MTBM, A_o, etc)?

28. What has been the overall achieved reliability of the fielded system for its entire life cycle thus far?

29. How is reliability field data collected to gather failure and repair histories? (Please check all that apply)

- Intermediate Supply/Maintenance Activities
- Reliability Data is Not Formally Collected
- Depot or CLS Maintenance Records
- Other (Explain)
- Using Unit Readiness Reporting

30. Does current achieved field reliability data indicate your system meets, exceeds, or has failed to meet the ORD reliability requirement?

- Achieved reliability has exceeded ORD requirements
- Achieved reliability has met ORD requirements
- Achieved reliability has fallen short of ORD requirements

○ Reliability data not formally collected

○ Requirements were not delineated in the ORD

Additional comments:

31. Does current achieved field reliability data indicate your system meets, exceeds, or has failed to meet the contractor reliability estimate?

○ Achieved reliability has exceeded contractor estimates

○ Achieved reliability has met contractor estimates

○ Achieved reliability has fallen short of contractor estimates

○ Reliability data not formally collected

○ Contractor estimates have not been maintained for comparison

Additional comments:

32. What specific organization(s), if any, have compared and assessed actual achieved reliability of fielded systems to the original contractor estimates?

If completed, was it done as an official responsibility/role assigned by higher headquarters or was the comparison conducted for some other reason (i.e. internal study)? Please explain.

33. Has the system undergone a Depot Level Maintenance Program (SLEP/PIP/Rebuild/IROAN)?

○ Yes ○ No (If so, which one and at what stage/year in its life cycle?)

34. Following any Depot Level Maintenance Program, has the achieved reliability of the system drastically changed? ○ Yes ○ No (If yes, please explain)

35. Has any of the reliability failure data collected led to identification of O&S cost drivers that subsequentl led to cost effective improvements?

○ Yes (Please explain in more detail)

○ No

Additional comments:

36. Is there a formal reliability growth program for your system? (i.e. FRACAS)

○ Yes (If yes, where is it documented?)

○ No

Additional comments:

37. Does your system employ a Reliability Centered Maintenance program?

○ Yes (If yes, how is it formally implemented?)

○ No

Additional comments:

Submit Reset For more information contact (Capt Marvin Norcross) Date last edited: 10/03/02

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APPENDIX C. MARINE CORPS MATERIEL COMMAND MTBF/MAINTENANCE STUDY

D0209 (MK-48) MEAN TIME BETWEEN FAILURES/MAINTENANCE STUDY

Assigned: 8 June 2002
Completed:
Completed by: Capt Jake Enholm
Assisted by Jaeyong Lee, Assistant Professor of Statistics, Penn State, Maj Humpert, Capt Paige, Capt Frey, CWO-2 Peterson, Deborah Whitley, Mike Everly, Dennis Cooper, GySgt Pelligrin.

Objective: Formulate a methodology for determining systemic mean time between failures and equipment parts (NSNs) failure rates using MIMMS/ATLASSII/SASSY data fields.

Data Used: D0209 ERO (Equipment Repair Order) Data from 1999-2001
Number of Records: 34,592.

INTRODUCTION

This study was conducted in order to determine whether mean time between failures for a primary end items using current warehoused maintenance management data is possible. The study was also conducted to determine whether mean time to failure for a particular part on a primary end item using the same data is possible.

It is important that the study includes the reason why we are attempting to calculate mean time between failures for equipment. The calculation of this time is necessary in order to determine whether the mean time between failures is increasing, decreasing, or remaining constant with age. As equipment ages, its mean time between failures decreases until the cost of keeping that item operational is more than the cost of buying a new item. Estimates of when maintenance costs will exceed acquisition costs are questionable without mean time between failures calculation. Each piece of equipment we are concerned with is a system of working parts, and we refer to its failure as a *systemic* failure. A complete estimate of maintenance costs should concentrate more on mean time between maintenance instead of mean time between failure in order to capture all costs.

Mean mileage between failures vice mean time between failures might be a better indicator for item replacement in some equipment, such as trucks. It was established in an earlier study that the MK-48 meter reading field of the Marine Corps Integrated Maintenance Management System (MIMMS) and ATLASS II data that records odometer information was unusable for most records (Enholm, 2002). It might be possible to construct a sophisticated algorithm to determine a mean mileage for the fleet, but the nature of the current study requires lower error rates than are currently found in the meter

reading field. It is this reason why mean mileage between failures cannot be accurately determined at this time.

The calculation of mean time to failure for a part in a system is important in order to statistically isolate a problem area. Mean time to failure calculation is also important when comparing the amount of time we can expect a part to be in operation, compared to its cost.

In the calculations used in this study, mean time between failure (MTBF) and mean time between maintenance (MTBM) periods were combined. The addition of the deadline control date field can be used to tell if a vehicle is deadlined or just operating in a degraded fashion. The deadline control date field is left blank on equipment repair orders (EROs) that are not deadlined. This study substitutes median time between failures/maintenance for mean time when discussing alternate methodologies.[1]

SYSTEMIC MEAN TIME BETWEEN FAILURE/MAINTENANCE

The calculation of a time to failure/maintenance of an item requires that we know the time an item has been in operation. For systemic failure or maintenance degradation there is also a requirement that the age of the system be established. This is particularly important when attempting to establish the age when an item starts spending longer and longer times down as it gets older, and maintenance starts adversely affecting operations.

Unfortunately, there is not a central repository or data warehouse where the Marine Corps has information establishing the age of a serialized item. The program managers of an item keep a logbook of serial numbers that detail when a serial number was fielded. This information is not always in electronic format, or readily available. For this particular study, information from MARCORSYSCOM helped establish the number of MK-48s that were fielded between the years 1985 and 1999.

1985	287
1986	354
1987	434
1988	574
1989	31
total	1680

Table 1. MK-48 Fielding Numbers by Year.

These numbers were used to estimate the year a serial number was fielded. Estimation had to be done in this case because no database was available that specifically contained this information.

Serial numbers are given sequentially as an item is fielded. Using the number of MK-48s fielded each year combined with the serial numbers found in the ERO header

[1] Statistically, this is not the same number. The sample median time between failures is a point in time where 50% of the samples fail. The sample mean time is the average time between failures. Because we cannot always calculate the mean reliably when using certain statistical methods, we will sometimes have to substitute a median as the most reliable substitute.

records, a table was constructed that estimated the ages of the serial numbers from 1985 - 1989.

Serial Number	Yr Fielded
515814	1985
515842	1985
516137	1985
516188	1985
516276	1985
516367	1985

Table 2. A Portion of the MK-48 Serial Numbers – Year Fielded Table.

These were estimated by sorting the serial numbers found in maintenance management data and counting them out according to the totals in Table 1.

The maintenance cycle of an item such as the MK-48 is commonly referred to as a repairable process because the item transitions between operating and non-operating status. The model used here is a maintenance model, where both preventive and corrective maintenance actions are applied to systems being studied. Leemis (1997) advocates the use of a non-homogeneous Poisson process to model failures for repairable systems since it can model deteriorating systems. Non-homogeneous means that the time between failures can increase or decrease. For a definition of a Poisson process, see Appendix A.

Once the age of a vehicle has been established, the time between failures can be correlated with the age of the vehicle if a wide enough data range is established. Unfortunately, although the Marine Corps has maintenance management data warehoused back to 1998, the data from 1998 appears to be incomplete. There were between 8000-13000 equipment repair order (ERO) records recorded for MK-48s from 1999-2001. But in 1998 there were only 1400 records, suggesting that the warehousing was incomplete and the 1998 data should not be used. This assumption reduced our available data range to 1999-2001.

Systemic failures were compiled using the assumption that a group of EROs with a common serial number and the same date received in shop (DRIS) entry consists of one job for a particular vehicle. The time between DRIS and the date the job was closed (all the EROs for that job are closed out) is also of particular value. The number of days the vehicle was worked on for a particular job reduced the amount of time that the vehicle was available. In general, if two EROs have overlapping dates, the dates that cover the largest period of time are used for failure calculation.

CENSORED AND UNCENSORED DATA

The use of data from 1998-2002 involves the use of *censored* data. Censored data involves the use of incomplete amounts of time in some samples because our records stopped at a particular date. If we have a serialized piece of equipment, such as MK-48

515814, and we know when in 2001 it was worked on, but we didn't see it worked on again before we ended our study in 2002, then we say our data is *right censored* for that period of time. If we have another serial number, 515842, and we know it was worked on once in 2001, and again in 2002, then we know the amount of time that serial number was running before it was worked on again. We say that that sample was *uncensored*. Both censored and uncensored observations provide clues to generating a mean or median time between failure/maintenance. The statistical calculations were done using Kaplan-Meier survival estimates, which estimate the probability that an item will survive to a particular time by conditioning on the probability that it survived up to the previous period. For more information, see Kaplan and Meier, 1958.

Kaplan-Meier survival statistics were a useful tool to describe the MK-48's failure/maintenance periods. Figure 1 shows the Kaplan-Meier (K-M) survival probabilities for operating a MK-48 up to a particular day based upon maintenance management system data from 1999. Data calculation for a median for 1999 data was attempted, to see if a distinct median for every year of warehoused data could be isolated. If so, we could see if the medians for several years were non-homogenous. The gaps on the right part of the graph show the censored data observations. A median time to failure could not be calculated because there were too many censored observations.

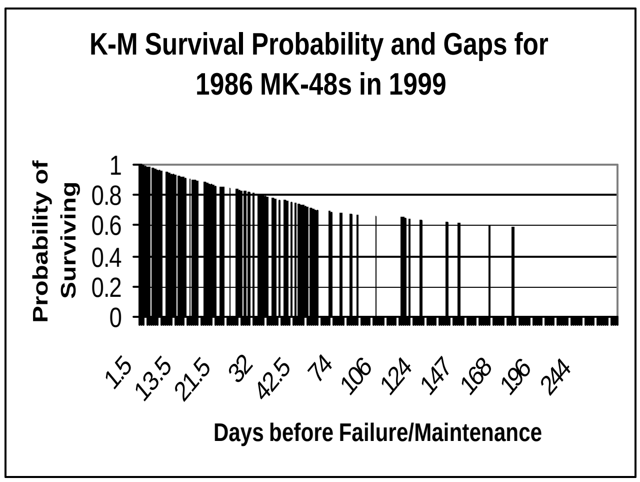

Figure 1. Kaplan-Meier survival probabilities showing the probability that a MK-48 fielded in 1986 will operate up to a certain day before needing maintenance. The data used was from 1999 maintenance EROs. Data that was censored, or incomplete shows up as gaps. The large amount of censored data did not allow a median to be calculated.

Because a median could not be calculated using just the 1999 data, the data period was widened to include 1999-2001. Table 3 shows the results of that analysis.

Percentiles of (all years) the Survival Function	
	Survival Time
25'th percentile (lower quartile)	87
50'th percentile (median)	181
75'th percentile (upper quartile)	1111

Table 3. Analysis output from the software program *Statistica* showing Kaplan-Meier survival statistics for MK-48s, using maintenance management data from 1999-2001. The statistics reflect a median time to failure/maintenance of 181 days.

The median time between failure/maintenance of MK-48s of 181 days seemed excessive given current readiness rates, however it must be taken into account that this rate includes all MK-48s in the Marine Corps. The Mk-48s in stores, and on Maritime Pre-positioning Force (MPF) ships might be affecting this trend. Acquisition of an additional data set that filters out stores and MPF ship MK-48s is required to test this hypothesis.

It was also possible to calculate the median time between failures/maintenance for a group of MK-48s fielded in a particular year. The expected median times between failure/maintenance should be decreasing with age. Figure 2 shows that this is indeed the case, with the exception of MK-48s that came out in 1987. (This excludes vehicles fielded in 1989 because the low number of vehicles fielded in that year)

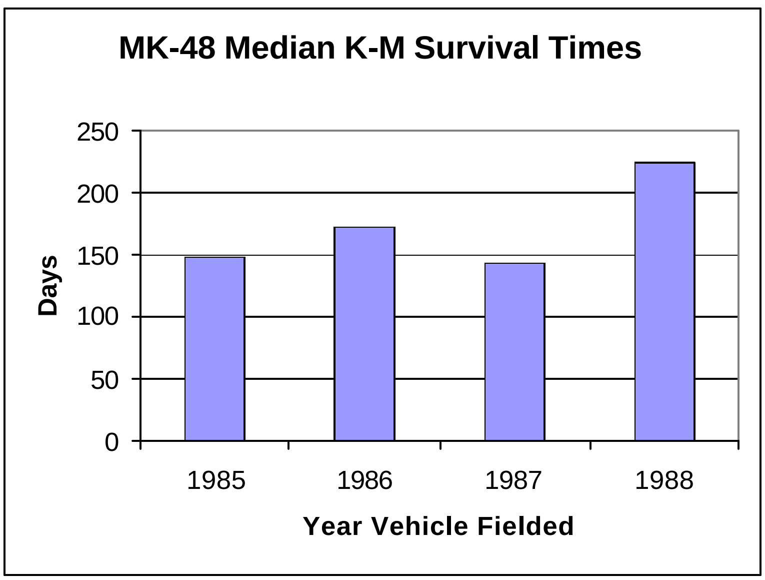

Figure 2. Median K-M times between failure/maintenance correlated with estimated age. The median times decrease with age, with the exception of vehicles fielded in 1987.

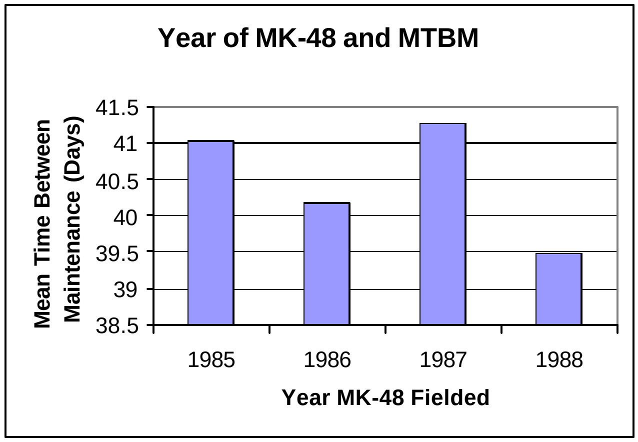

Figure 3. Mean times between failure/maintenance correlated with estimated age using the average observed times and discarding the censored observations. The Kaplan-Meier method was not used here. The mean times do not decrease with age, but the values are more reasonable given current MK-48 readiness rates.

An alternative method to the K-M methodology was also used. This methodology discarded the censored observations and used only samples that contained two jobs or more. The amount of time the vehicle was operational between jobs for a similar serial number was calculated. This time was then averaged for all observations. The sample mean for this method was 41.2 days. The mean seems more reasonable with current readiness levels for the fleet, but this methodology did not show increasing MTBF/M for increasing age.

A possible validation of tying in a set of EROs with a similar serial number and the same DRIS date as one job was seen. The jobs were correlated with the amount of time each vehicle was worked on. An average readiness for the fleet was calculated using the amount of time worked on for each job. This calculation was adjusted for a data period that corresponded with archived MK-48 readiness in the Material Readiness Assessment Module (MRAM). The job-methodology calculated readiness was 82%. The MRAM readiness for the same period of time was also 82%. It should be noted that the MRAM only uses deadlined vehicles, and the data used in this study was for all maintenance tasks. Further calculation with another primary end item is necessary before any conclusions can be made on this validation process.

NSN TIME TO FAILURE

The equipment repair order records were "drilled down" or linked to National Stock Numbers (NSNs) that were ordered for a particular ERO. This would not have been possible to compile in a short period of time without the help of the integrated SCOPE database constructed by Capt Paige's team. The necessary data was compiled with the integrated system in three minutes. A parallel effort using the conventional maintenance management record data system in place required two weeks.

Calculation of a mean time to failure of an NSN was done under the assumption that the NSN failed and another was ordered and replaced the failed item. This did not include the repair cycle used in secondary repairable items (secreps) such as engines and transmissions. Calculation of a mean time to failure for an NSN is problematic because there might be several NSNs that are in use for a particular system that perform the same function.

A common statistical method for modeling lifetimes of equipment parts is the Weibull distribution, which is a "…generalization of the exponential distribution…" (Leemis, p. 88). The Weibull distribution was selected for modeling two of the most common NSNs found in the MK-48 maintenance records. Table 4 is a partial printout from the statistics software program *Statistica* and shows parameter estimates that *Statistica* came up with after looking at the data from the selected NSN. The low p-values (also known as *observed significance levels*) on the right indicate that the data does not fit the Weibull distribution well. The NSN chosen was one of the most frequently encountered ones in the data set. Figure 4 shows the survival probability distribution for these samples.

Parameter Estimates, Model: Weibull (nsn1)						
Note: Weights: 1=1., 2=1./V, 3=N(I)*H(I)						
		Variance	**Std.Err.**			
	Lambda	**Lambda**	**Lambda**	**Chi-Sqr.**	**df**	**p**
Weight 1	0.000662	3.2E-07	0.000565	18.33028	9	0.031563
Weight 2	0.000747	2.09E-07	0.000457	19.10768	9	0.024322
Weight 3	0.001918	2.01E-06	0.001417	19.23488	9	0.023297

Table 4. *Statistica* parameter estimates for a MK-48 Weibull lifetime distribution. The low p-values indicate a low level of confidence that the NSN distribution fits a Weibull curve.

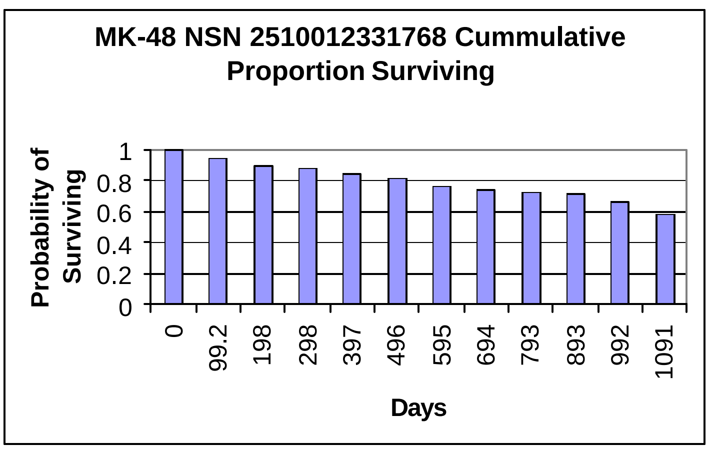

Figure 4. Weibull probability of NSN 2510012331768 surviving up to a particular day.

A second MK-48 NSN that was frequently ordered was analyzed. The high p-values that *Statistica* generated indicate that the data was close to a Weibull distribution with the chosen parameters. *Statistica* gave this NSN a median life time of 1118 days. Figure 5 shows the survival probabilities for the parameters in Table 5.

Parameter Estimates, Model: Weibull (nsn2)								
Note: Weights: 1=1., 2=1./V, 3=N(I)*H(I)								
		Variance	Std.Err.		Variance			
	Lambda	Lambda	Lambda	Gamma	Gamma	Chi-Sqr.	df	p
Weight 1	0.000791	1.07E-06	0.001035	0.864681	0.040519	6.143479	9	0.725468
Weight 2	0.001402	1.37E-06	0.001171	0.789683	0.015711	5.995469	9	0.740362
Weight 3	0.001913	2.82E-06	0.001679	0.728864	0.017097	6.031236	9	0.736779

Table 5. *Statistica* parameter estimates for a MK-48 Weibull lifetime distribution. The high p-values indicate a high level of confidence that this NSN distribution fits a Weibull curve.

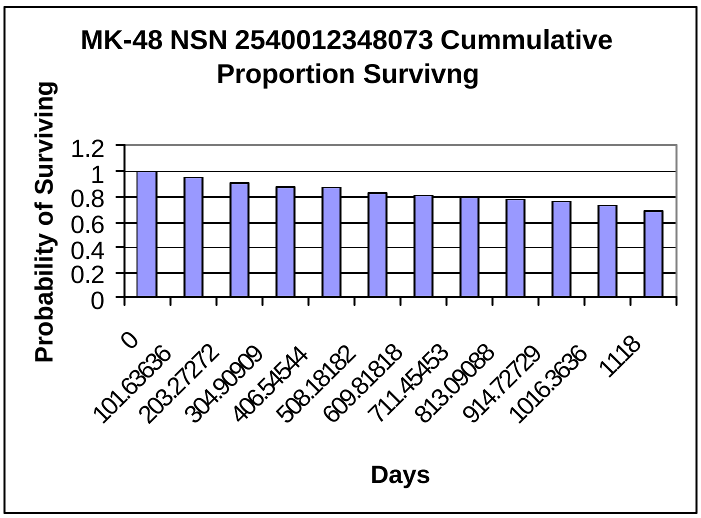

Figure 5. Weibull probability of NSN 2540012348073 surviving to a particular day. The median (not the mean) number of days for survival was 1118 days. This number indicates the curve's downward trend is steeper after 1118 days.

CONCLUSIONS AND RECOMMENDATIONS

The mean-time between failure/maintenance analysis of the MK-48 revealed some areas where maintenance management data systems can be improved. The improvements will make this type of analysis more accurate, and more useful with respect to estimating when a system's mean time between failures/maintenance is increasing or decreasing with age. The study produced two different methodologies to calculate time between systemic maintenance/failure. The analysis of MK-48 NSNs and their median time to failure also revealed some areas that can be beneficial to producing

useful results.

The following recommendations would increase the accuracy of systemic and NSN failure rate calculation:

1) A database containing primary end item serial numbers, the year fielded, and their cost needs to be developed. A second database where the NSNs of a primary end item, their description, and their cost needs to be constructed. NSNs that perform the same function need to be cross-referenced.

2) The current warehoused maintenance data of the Marine Corps needs to be extended back in time as far as possible.

3) Perhaps the best alternative for error checking of serial numbers will be provided with the implementation of the Global Combat Support System-Marine Corps (GCSS-MC). The GCSS-MC system will replace our current legacy maintenance systems and could contain serialized records for each primary end item in the Marine Corps. If a manpower-type record of information for a serial number can be checked when a new ERO is entered, a calculation can be done to see if the new entry makes sense. A sophisticated algorithm known as an *intelligent-agent* can run through a series of decision trees that look at past dates and entries for meter readings for that serial number. The intelligent agent then makes a decision whether or not a meter reading is reasonable for that serial number. If not, a notification back to the Maintenance Management Officer of the unit that made the entry can be sent with a request for clarification of the new entry.

It is possible to calculate a sample mean or median time between failures/maintenance for some of the equipment in the Marine Corps using the methodologies presented in this study. The accuracy of such analysis will be suspect if the current weaknesses of the system are not fixed. A validation of the most accurate method is currently being conducted.

APPENDIX A

Ross defines a Poisson process as a "The counting process $\{N(t), t=0\}$ is said to be a *Poisson process having rate* ?, ? > 0, if

i. $N(0) = 0$
ii. The process has independent increments
iii. The number of events in any interval of length t is Poisson distributed with mean ?t. That is, for all s, $t = 0$

$$P\{N(t+s) - N(s) = n\} = e^{-lt}\frac{l}{n!}t, \quad n = 0,1\ldots"$$

Notes on Julian Dates

A challenge encountered was the way dates are entered into EROs. At the time MIMMS was implemented there were many reasons why a Julian dating system was used for date entries. In the year 2002, the system is a hindrance and not necessary. The way the system works now, the mechanic takes a standard date and with the use of a Julian date calendar converts the date and inputs it into the system. Then the individual looking at the data looks at the Julian date and converts it back into a standard format that is understandable.

The Julian date format is also problematic when using it in Excel or Access, the two most common forms of data manipulation software. Excel can calculate the number of days between two dates by simply subtracting the two date in standard month/day/year format. Excel automatically does the rest. When the date is in Julian format, string extraction functions must be used that convert the field into standard month/day/year and then the calculation can be performed. The strings that the Julian dates are stored in are also problematic. Excel has a problem properly sorting these strings.

MTBF/M FORMULATION

Indices

j	job number
y	year of job
s	serial number of equipment

Variables

$a_{j,y,s}$	The date that an ERO or group of EROs in a job was opened. The date the group of EROs was opened should be the earliest date received in shop (DRIS) in the group. Job *j* in of equipment in year *y* with serial number *s*.
$O_{j,y,s}$	The date that an ERO or group of EROs in a job was closed. The date the group of EROs was closed should be the latest date in the group. Job *j* in of equipment in year y with serial number *s*.
$D_{j',y,s}$	The number of days between jobs j and $j + 1$.
$C_{j,a,y,s}$	Censored time for job *j*, in year *y*, for serial number *s*. This is the time from the date the job was closed to the end of the data taking period.
N_s	Total Number of Jobs for a serial number.

L Total number of serial numbers in equipment being analyzed.

d Censoring indicator: 1= censored, 0 = uncensored.

T_s Survival time observation for serial number s.

Formulation

$D_{j',y,s} = a_{j+1,y,s} - O_{j,y,s}$ Calculation of the number of days between jobs

$X_s = \sum_{j'}\sum_{y}\frac{D_{j',a,y}}{N_s - 1}$ Calculation of mean number of days per job for a particular serial number.

$T = \min(X,C)$ The minimum value between X and C is picked for T.

$d = I(X \le C)$ If X is less than C then $d = 0$, else $d = 1$.

Two methods were used for comparison of systemic mean time between failures/maintenance in this study:

1) l_0 = Kaplan-Meier (K-M) product limit estimate for $T = \min(X,C)$ and $d = I(X \le C)$
2) $l_0 = 1/X_s$ = The inverse of the average days between jobs for the observed samples. This methodology discards the censored observations.

$1/l_0$ Mean Time Between Maintenance/Failures for equipment with age a. (Method 2 only)

Notes from calculating systemic Median Times Between Failures/Maintenance:

1) Averaging the number of days between jobs on the same serial number does not calculate points from censored observations that might result from the date that the last job was closed until the end of the data period. These points are not taken into account.

2) The survival data generated with a Kaplan-Meier distribution implies that the missing observations need to be extended by increasing the warehousing of data back in time in order to get this data. A median can be calculated from the current data set, but it would be better to get a median from each year in the data set.

APPENDIX B

Notes from calculating part (NSN) failures:

1) NSNs were calculated by separation from the main data set and sorted by serial number of vehicle they were mounted on.

2) If an NSN was mounted on the same vehicle two times or more the number of days it lasted before another NSN with the same number was mounted on it was used as an observation.

3) If an NSN was mounted on a vehicle and left there until the data period ended we count the number of days between the date the job was closed and the date the last piece of data was collected. This data is annotated as being right censored.

4) What if the part wasn't the same one that was mounted before? For example we replaced the right headlight, then the left headlight goes out and we replace that? We have no way of telling.

5) What if the NSN was replaced by a different NSN for some reason? We don't know this, but it can be fixed with an NSN database.

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